Prd w/Spec Rep

EFFECTS OF I-90 CONSTRUCTION ACTIVITIES ON SPAWNING SUCCESS OF KOKANEE (ONCORHYNCHUS NERKA) IN COEUR D'ALENE LAKE

FHWA-ITD-RP099

David H. Bennett
and
Peter F. Hassemer

Department of Fish and Wildlife Resources
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, Idaho 83843

in
cooperation with the

Idaho Department of Fish and Game

Idaho Transportation Department

and

The Federal Highway Administration

October 1982

TABLE OF CONTENTS

ABSTRACT

The effects of newly placed fill material from I-90 construction activities on spawning utilization and success of kokanee (Oncorhynchus nerka) were investigated from October 1980 through June 1981 in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Four study sites were established, one site was at the newly created construction site, one at an older highway fill, and two additional sites in areas unaltered by highway construction activities. At each of the study sites, underwater photographs were taken during the peak of the kokanee spawning season to characterize the spawning substrate and assess the extent of substrate utilization by spawning kokanee. Also, embryos were planted in the substrate at the various study sites to quantify survival to the eyed egg and pre-emergent fry stages, and emergent fry traps were used to quantify emergence success. Results of water quality analyses of interstitial water samples were compared among sites.

Utilization of newly placed highway fills by spawning kokanee was similar to that in other areas surveyed. At all sites, kokanee manifested preference for substrate with a range of median (D50) particle sizes from 21-90 mm of relatively homogeneous composition (sorting coefficient = 0.50-1.05).

Survival of kokanee embryos to the eyed egg and pre-emergent fry stages was similar between newly placed and older highway fills, and survival at all highway fills was higher than from unaltered areas. However, significantly lower survival to the pre-emergent fry stage was found at deep water (13-16 m) sites than shallow water (<7 m) sites.

No adverse water quality conditions could be attributed to the new and old highway fills. Values of pH and concentrations of alkalinity, acidity, dissolved oxygen, sulfate, and ferrous iron were generally similar among sites but generally differed with time.

These results suggest that alterations to the shoreline of Coeur d'Alene Lake by highway construction activities have enhanced survival of kokanee embryos. Our studies indicate that further alterations to the shoreline of Coeur d'Alene Lake by highway construction activities could be conducted with additional beneficial effects to spawning, incubating, and emerging kokanee if fill were of similar size,design criteria and mineral composition to that used for fill in this study. We recommend that if future shoreline alterations occur, that "preferred" size substrate (21-90 mm) of relatively homogeneous composition (sorting coefficient = 0.50-1.05) be placed in the upper 10 m (from summer pool) of Coeur d'Alene Lake.

INTRODUCTION

Kokanee (*Oncorhynchus nerka*), landlocked sockeye salmon, have made a significant contribution to the sport fisheries and economy of northern Idaho. Priest, Pend Oreille, and Coeur d'Alene lakes have received wide recognition for providing excellent kokanee fishing. Kokanee were first introduced into Coeur d'Alene Lake in 1937. Catch rates were low during the early years of the fishery until the 1950's and 1960's when fishing success increased. In 1967, 242,000 kokanee were harvested from Coeur d'Alene Lake (Mallet 1968), and by 1979, an estimated 600,000 kokanee were harvested from the lake (Rieman and LaBolle 1980). Although the Coeur d'Alene Lake fishery has improved, catch rates in Priest and Pend Oreille lakes have declined to 0.3 and 1.4 fish per hour, respectively. This decline has placed increasing interest and fishing pressure on the Coeur d'Alene Lake kokanee stock.

Early in the development of the kokanee fishery on Coeur d'Alene Lake, biologists felt that hatchery fry releases were sustaining the fishery (Bowler 1980). By the mid-1970's, however, it became obvious that the fishery was being supported by natural reproduction. Surveys in Coeur d'Alene Lake by Idaho Department of Fish and Game and University of Idaho personnel suggested that the Wolf Lodge Bay area was the single most important area for spawning and rearing of juvenile kokanee. For example, at least 76% of the kokanee fry recruitment to Coeur d'Alene Lake in 1979 originated from Wolf Lodge Bay (Bowler 1980).

SCUBA surveys conducted along the shoreline of Wolf Lodge Bay during the 1979 kokanee spawning season (mid-November through early January) revealed heavy utilization of fill material from previous road construction for spawning (Hassemer and Rieman 1980). The "road-fill" substrate used for spawning consisted of angular fractured material, having characteristics which probably enhanced embryo survival by allowing good interstitial water exchange.

Planned upgrading of Interstate 90 along the Wolf Lodge Bay shoreline included placement of additional fill material into the lake. One section of shoreline along Interstate 90 to be covered with fill material was previously identified as a heavily utilized kokanee spawning area. Because of the interest in kokanee in Coeur d'Alene Lake, concern was voiced over the possible damaging effects of this habitat alteration on the spawning ecology and success of kokanee. As a result of this concern, this study was initiated in the fall of 1980 to examine the effects of adding additional fill material to a portion of the north shoreline of Wolf Lodge Bay on kokanee spawning success. Specific objectives of this study were:

1) To characterize spawning substrate of kokanee in Wolf Lodge Bay;
2) To evaluate utilization of the I-90 fill material in Wolf Lodge Bay by spawning kokanee;
3) To compare kokanee embryo survival and emergence success from "newly" altered habitats with those from other areas; and,
4) To assess the effects of further alterations of shoreline habitat in Coeur d'Alene Lake on the kokanee salmon population and develop recommendations for mitigation of possible habitat losses.

STUDY AREA

Coeur d'Alene Lake lies in the northern panhandle of Idaho (Fig. 1). The lake, 12,743 hectares in surface area, is 46 km long and averages 1 km in width. Mean depth is 24 m. The lake is considered mesotrophic (Rieman 1980). A dam was built on the lake outlet in 1903 for electrical power generation, which has resulted in an annual lake level fluctuation from 2 to 3 m.

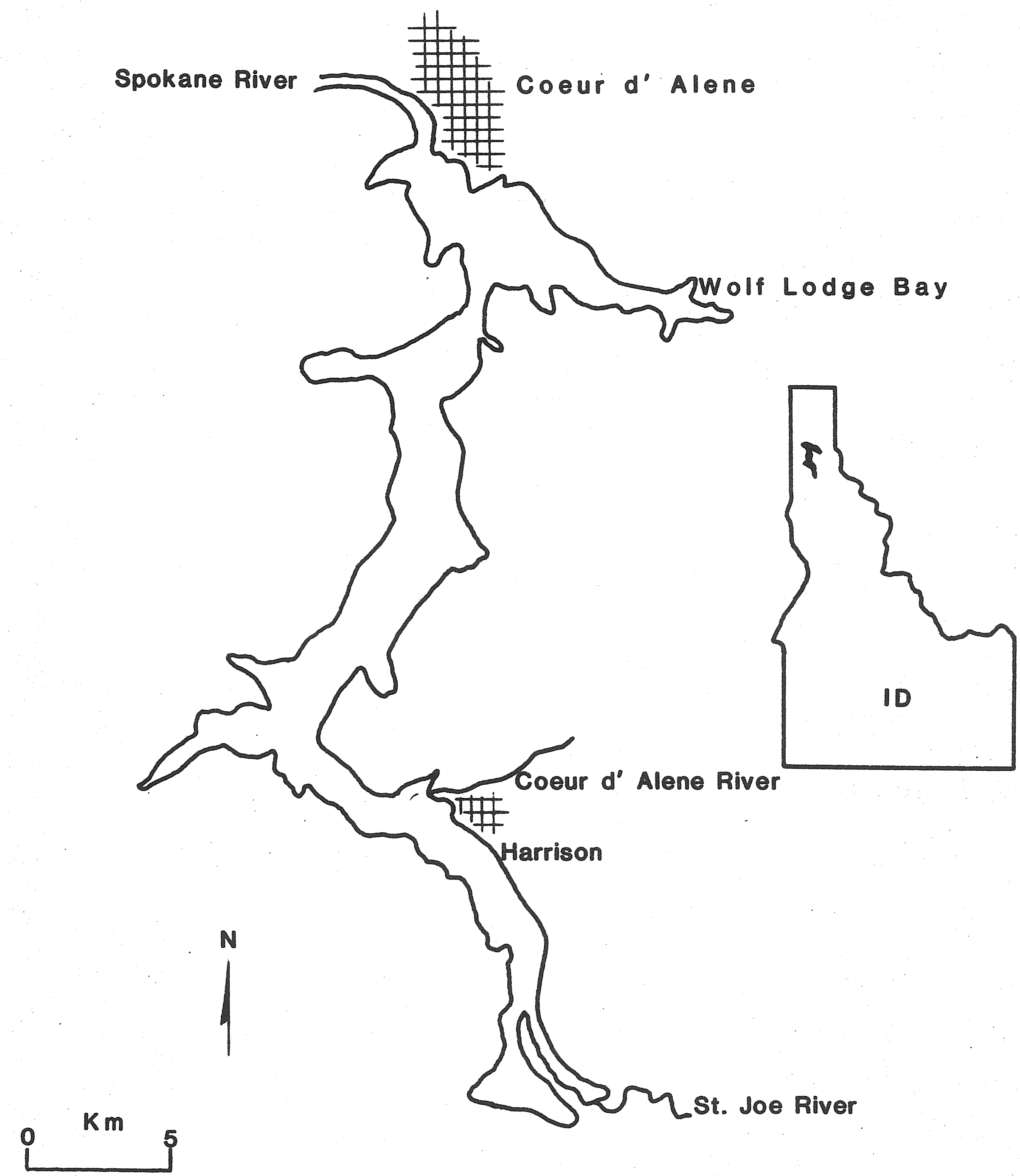

Figure 1. Map of Coeur d'Alene Lake showing the general location of the lake and Wolf Lodge Bay.

Major sport fish in the lake are kokanee salmon and Westslope cutthroat trout (Salmo clarki lewisi). As well as supporting a high yield kokanee fishery, the lake also receives a large amount of recreational boating activity because of its proximity to large population centers of northern Idaho and eastern Washington.

Wolf Lodge Bay, on the north-eastern end of the lake, is a unique section of the lake (Figure 2). Much of the Wolf Lodge Bay shoreline has been altered as a result of highway construction. Large amounts of "fill" material have been placed in the lake in several areas as a result of highway construction; the fill material originates from rock formations in the immediate area. The mineralogy of the rock formations of the Wolf Lodge Bay area is unique in that these formations are part of the western-most exposure of the Prichard Formation, part of the Belt Series rocks of western Montana and eastern Idaho. Whereas most of the Coeur d'Alene Lake shoreline is dominated by decomposed granitic material, the shoreline of Wolf Lodge Bay is characterized by quartzose argillite (Hobbs et al. 1965). Pyrite, common only to Belt Series rocks of the Prichard Formation, may constitute as high as 5% of the rock. These pyrite deposits caused concern because of their potential to influence pH concentrations. As stated previously, a major portion of the kokanee fry recruitment to the lake originates in Wolf Lodge Bay. Also, production of key zooplankton food items for young of the year kokanee peaks earlier and higher in Wolf Lodge Bay than in other areas of the lake. This zooplankton production is thought to enhance the survival of recently emerged kokanee fry (Rieman 1980).

Four areas of Wolf Lodge Bay were selected as study sites based on substrate characteristics and previous use by spawning kokanee (Fig. 2). Characteristics of the four sites are:

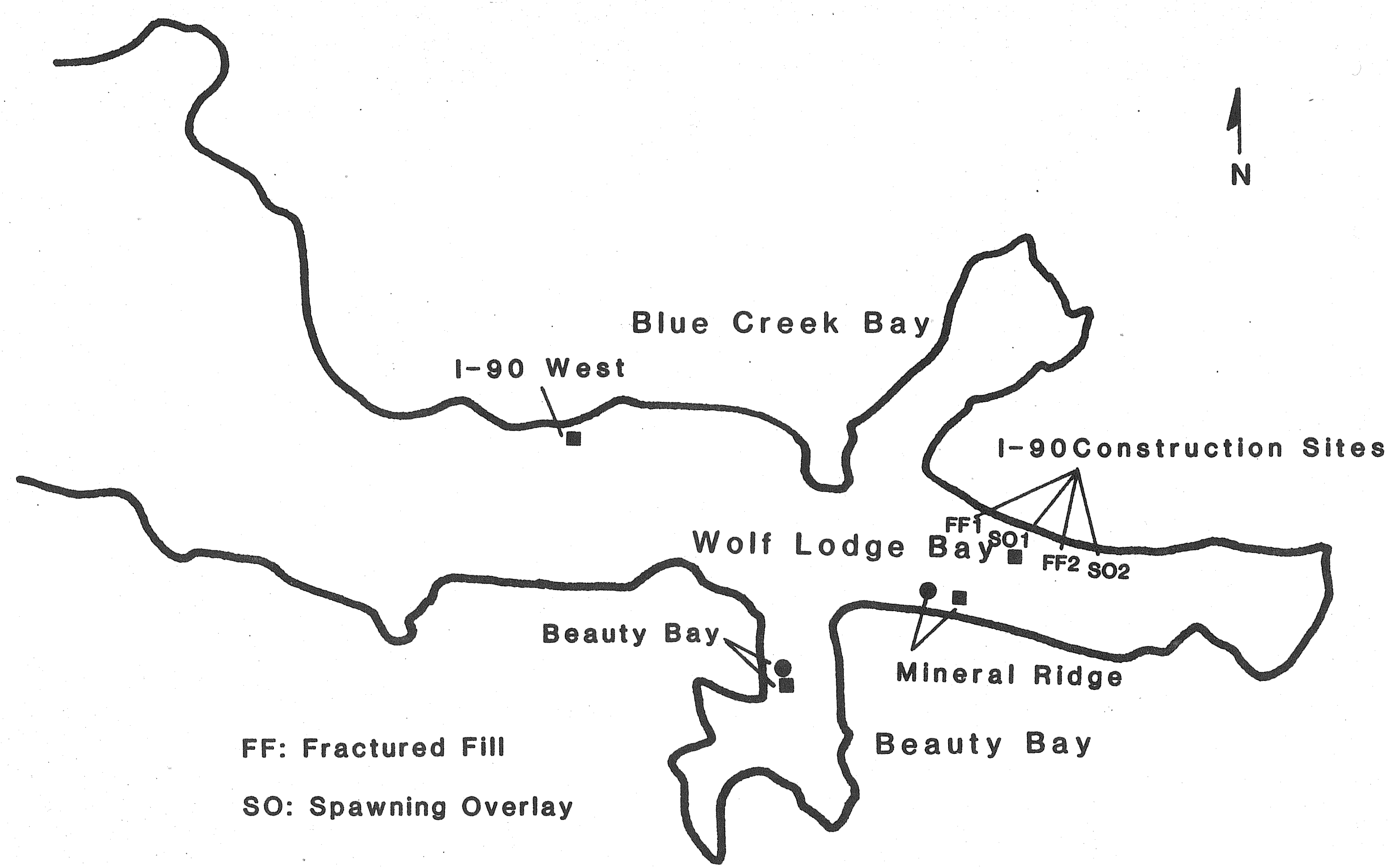

Figure 2. Map of Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, showing locations of embryo plants (circles and FF1, FF2, SO1, and SO2) and approximate areas where transects were located (squares) for substrate characterization and spawning utilization studies.

1) I-90 West - This site, along Interstate 90, lies on a small point extending into the lake and is 1.23 km from the west mouth of Blue Creek Bay. The site, undisturbed by road construction activities, is characterized by a series of small cliffs and ledges rather than a continually sloping bottom. Substrate type is fractured quartzose argillite. Slope of the bottom ranges from 45° to 60°.

2) Beauty Bay - This site, located on the west shoreline of Beauty Bay, is characterized by a steep but smoothly sloping bottom consisting of relatively finely fractured quartzose argillite. This finely fractured material is covered by approximately 2 to 3 cm of silt and fine sediments. The Beauty Bay site is a natural area undisturbed by construction activity. Slope of the bottom is approximately 50°.

3) Mineral Ridge - The Mineral Ridge site was on the south shoreline of Wolf Lodge Bay immediately east of the mouth of Beauty Bay. The bottom consists of a combination of boulder and gravel fill material (fractured quartzose argillite) from previous road construction. Substrate on the bottom is either predominantly boulder or gravel in composition. The boulders range in size from 0.1 to several meters in diameter, whereas, the gravel areas consist of materials less than 0.5 to 10 cm in diameter. Slope of the bottom is typically steep (45° to 60°).

4) I-90 Construction Site - The site of the present highway construction (upgrading of Interstate 90), along the north shoreline of Wolf Lodge Bay, extends from the east mouth of Blue Creek Bay east for

370 m. Slope of this new fill area is approximately 45° to 50°, with water depths at the toe of the fill ranging from 18 to 21 m. As a result of the construction in August and September, 1980, two substrate types were placed in the lake:

a) Fractured Fill - This material is composed of various sizes of fractured quartzose argillite removed from areas immediately adjacent to the construction site. Fractured fill covered 57% of the study site.

b) Spawning Overlay - A layer of round, washed gravel of a size suitable for spawning was placed over the fractured fill in specified areas. Location of areas where spawning overlay was to be placed was made by SCUBA divers. Areas were selected where the fractured fill was too large to be utilized by kokanee for spawning. Spawning overlay gravels were placed over the fractured fill, from the water surface to the toe of the fill, in strips of various width, resulting in alternating sections of fractured fill and spawning overlay gravels (Fig. 3). Depth of the spawning overlay ranged from 10 to 20 cm; the spawning overlay covered approximately 43% of the construction site.

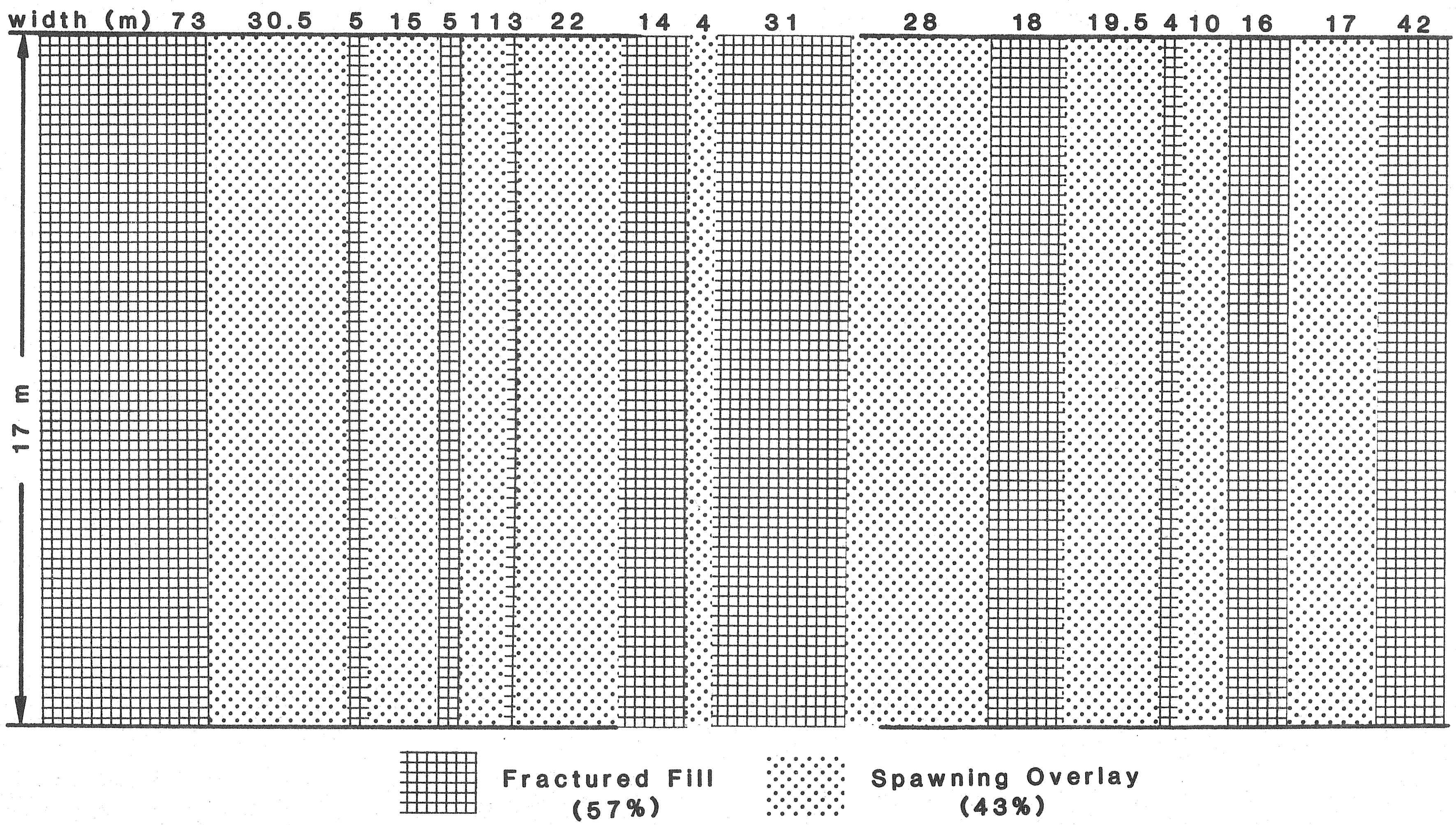

Figure 3. Approximate widths of fractured fill and spawning overlay substrates at the I-90 Construction site study areas, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho.

METHODS

Substrate Characterization

To characterize spawning substrate of kokanee in Wolf Lodge Bay, underwater photography was used. The location of vertical transects was randomly selected at each of the four study sites. Transects were established by placing on the substrate a weighted line, marked at 1 m intervals, from the surface to a slope distance depth of 17 m. Four transects were run on each of the I-90 Construction site spawning overlay and fractured fill substrates, three transects each were run at the Mineral Ridge and I-90 West sites, and two transects at the Beauty Bay site. SCUBA divers descended to 15 m on each transect and, using an underwater camera and strobe, photographed the substrate at 12 points at approximately 1 m intervals (slope) from 15 m to 3 m.[1] All substrate photographs were taken with a Nikonos IV camera equipped with an Oceanics 2001 strobe using Ektachrome 200, 35 mm slide film. SCUBA diving on all transects was completed during the first two weeks of December, the approximate peak of kokanee spawning activity. Each transect was systematically photographed as depicted in Figure 4. A gauge, calibrated to various sizes (2.54, 5.08, and 7.62 cm), was placed on each substrate site when photographed for later reference when projecting the photographs to obtain actual substrate sizes. After each photograph was taken, the site was excavated by hand to determine the occurrence of spawning. If kokanee embryos were present, the site was then classified as being used for spawning.

----

[1]Because of the homogeneity of the spawning overlay gravels, no photographs of this substrate were taken when the transects were run.

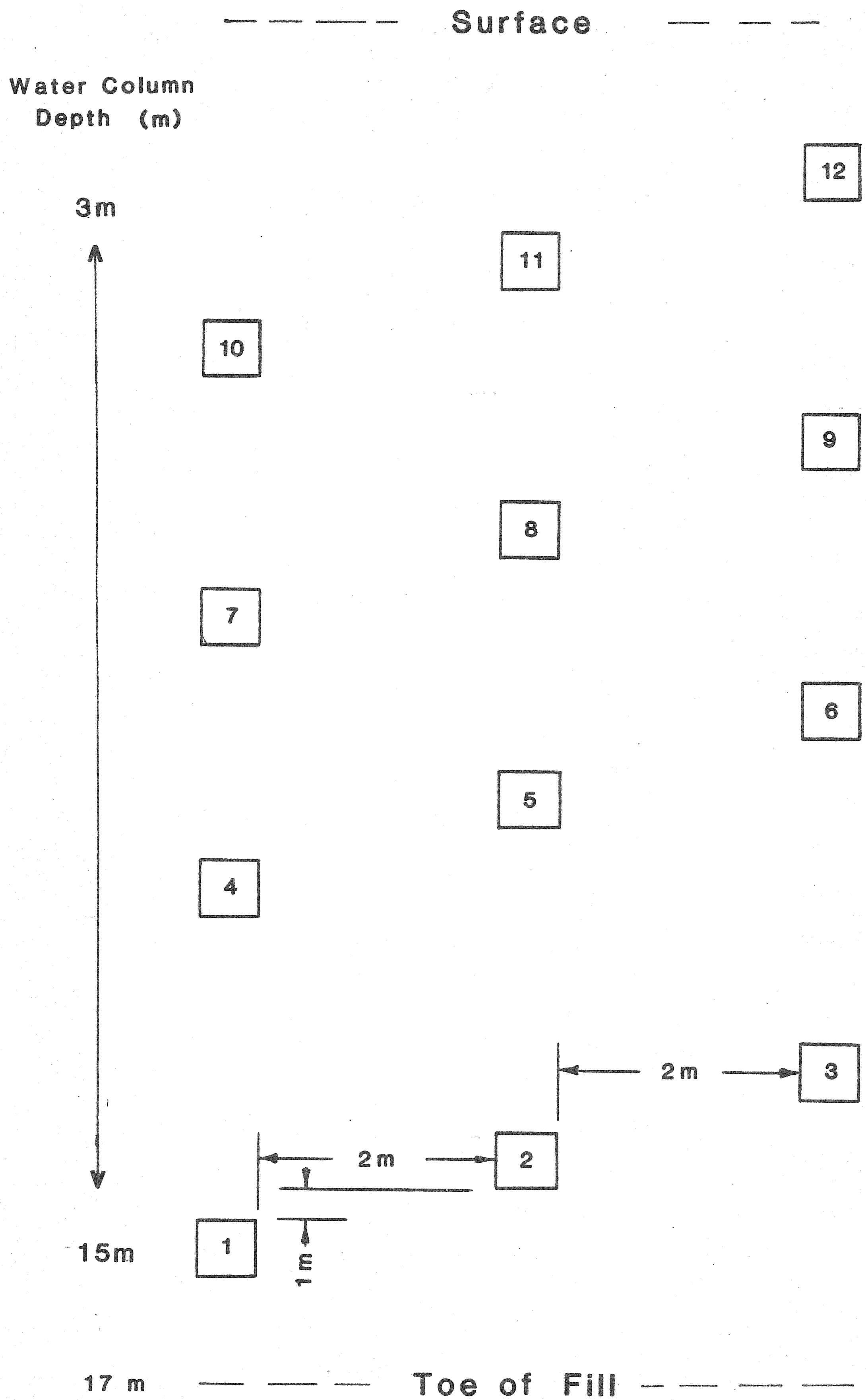

Figure 4. Sampling scheme used on all substrate characterization and utilization transects at the I-90 Construction Site, Mineral Ridge, Beauty Bay, and I-90 West study sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Numbers within boxes are sequence numbers.

Size classification of substrate was determined by projecting the slides at the actual size of the substrate materials (30.48 by 45.72 cm projected image) and measuring the size of all rocks within the center of the projection (17.78 by 30.48 cm rectangle). Horizontal and vertical lines were drawn across the center rectangle at 1.27 cm intervals, and the size of the rock (largest dimension) located at each intersection point of the grid system was measured and recorded. Measurements from each sample were arranged in particle size-frequency distributions (frequency expressed as percent of total) corresponding to the following particle size classes: 0-3.35 mm, 3.36-6.3 mm, 6.31-12.5 mm, 12.51-25.4 mm, 25.5-50 mm, 51-75 mm, 76-150 mm, and 151-300 mm.

Characterization of substrate was based on particle size-cumulative frequency distribution curves. The D16, D50, and D84 particle sizes were directly interpolated from these curves. These values represent the particle sizes which 16 (D16), 50 (D50), and 84% (D84) of the sample, respectively, are finer (Platts et al. 1979). D16, D50, and D80 values were determined for each photographic sample.

Wide variation in the shape of particle size distribution curves among samples made it necessary to include an additional parameter, a sorting coefficient, to describe the relative distribution of each sample. Sorting coefficients were calculated as:

$$SC=\log 10(D84/D16)$$

where SC = sorting coefficient, and D84 and D16 represent particle sizes as described above. Small values (approximately 1.0 or lower) of the sorting coefficient reflect samples with nearly lognormal particle size distributions. For lognormally distributed samples, 65% of the sample (by weight) would fall between the D16 and D84 particle sizes. Large values of the sorting coefficient correspond to heavy-tailed particle-size frequency distributions where some of the intermediate particle sizes may not be present in the sample. Samples with similar D50 particle sizes may differ considerably in overall particle size composition as reflected by the sorting coefficient (Fig. 5). The sorting coefficient is expressed as a logarithm to reduce its range as values of the quotient D84/D16 ranged from slightly greater than one to greater than 1000. We use the sorting coefficient as a <u>relative</u> measure of skewness of the particle-size frequency distribution.

Substrate Suitable for Spawning

Substrate Utilization

Utilization of the new fill material (I-90 Construction site) and the other study sites for spawning by kokanee was assessed along the transects. The number of photographic points on each transect that had been utilized for spawning (embryos found deposited within the area) was recorded. Utilization by spawning kokanee is expressed as the percent of total photographed points (for each site individually) that had been utilized for spawning.

Spawning substrate, as determined by the presence of kokanee embryos, was differentiated from other substrate based on the particle size composition, as defined by D50 particle sizes and sorting coefficients. Data from all four study sites were combined to characterize spawning substrate. Pooling the data enabled characterization of spawning substrate using the entire range of particle size compositions available and that selected by fish.

Preferred Substrate

To refine the range of substrate sizes being utilized for spawning, we determined the amount of "preferred" spawning substrate at each of the study sites. Preferred spawning substrate was defined as any substrate having a particle size composition similar to the most common substrate utilized for

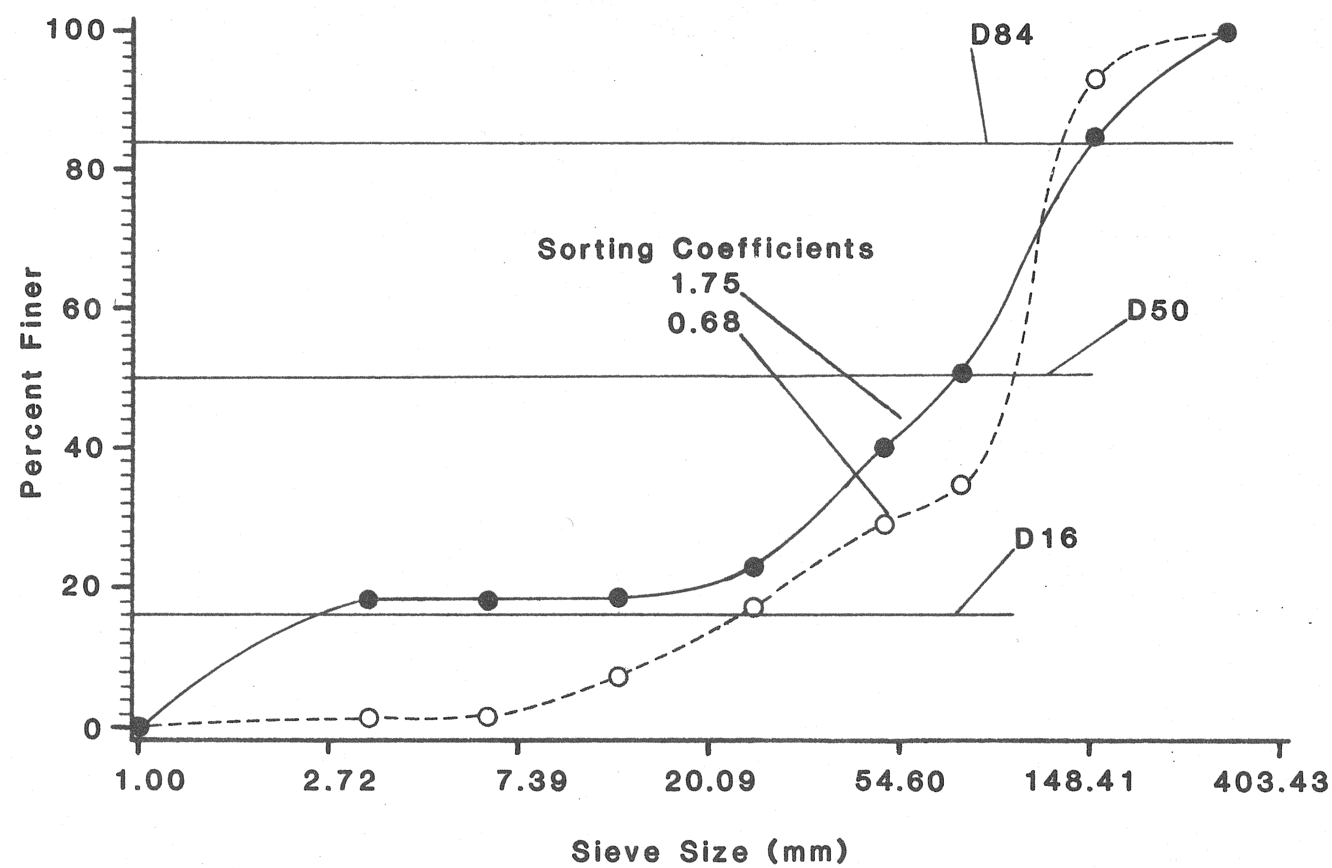

Figure 5. Particle size-cumulative distribution curves for two substrate samples (particle sizes determined using photographic techniques) from Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Y-axis represents the percent finer than each sieve size.

spawning at any of the four study sites and is expressed as a percent of the total area.

Another measure of utilization at the I-90 Construction site (fractured fill and spawning overlay) and the Mineral Ridge site for kokanee spawning was based on capture of emerging fry in randomly placed emergent fry traps (Stober et al. 1977). The emergent fry traps (Fig. 6) covered 1/4 m^2 of substrate and contained a removable cod end to allow retrieval of captured fry. Emergent fry traps were randomly placed on the substrate at the Mineral Ridge site (9 traps) and on I-90 Construction site fractured fill (15 traps) and spawning overlay (15 traps) substrates. Substrate material was placed around the base of each trap to secure its position and close any large spaces between the trap and substrate to preclude escape of trapped fry. Traps were checked by SCUBA divers weekly and all captured fry were enumerated and preserved in 95% ETOH for later analysis.

Extent of utilization of preferred spawning substrate was estimated by determining the percent of photographic points at which spawning occurred on preferred spawning substrate. Substrate at individual photographic points utilized for spawning was not necessarily composed of preferred spawning substrate.

Embryo Survival and Emergence Success

To compare kokanee embryo survival and emergence success from "newly" altered habitats with those from other habitats, embryos were artificially planted in each of the four substrate types at three of the study sites: Beauty Bay - natural undisturbed substrate; Mineral Ridge - old fill; and, the I-90 construction site - new fractured fill and spawning overlay. The influence of water column depth at the site of egg deposition on embryo

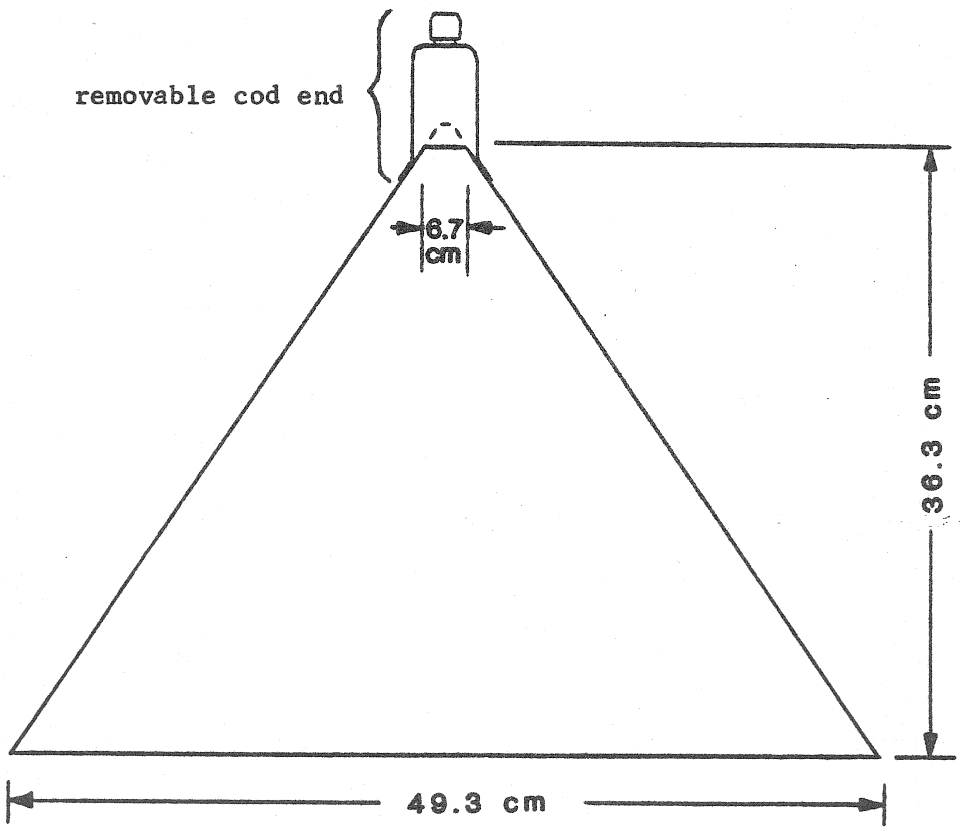

Figure 6. Fry traps used to capture emerging kokanee fry from artificially and naturally deposited embryos.

survival and emergence success also was assessed for each substrate type.

Recently fertilized eggs were placed in Whitlock-Vibert (W-V) hatching boxes (100 eggs per box) after water hardening. Eggs were taken from adults collected in the area and fertilized each morning prior to the days planting. Before placing embryos in the W-V boxes, each box was filled with substrate material taken from the site where the box was to be planted. Only viable embryos were counted into each box at the time of filling. Embryo plants were made on 1, 2, and 3 December, 1980, coinciding with the approximate peak of spawning activity. After all W-V boxes were planted each day, two W-V boxes were filled with 100 to 200 viable embryos and planted at the study sites as control boxes to quantify initial handling mortality. Control boxes were removed 2 days following planting and the number of dead and viable embryos enumerated. Initial handling mortality of embryos in the control boxes was low (mean = 2% for all control boxes) and, as a result, was not included in survival estimates.

A total of 174 Whitlock-Vibert boxes were planted by SCUBA divers. One hundred and twenty of these were planted at the I-90 construction site (Table 1). As a result, each substrate type had 2-15 box matrix configurations, one positioned in shallow and one in deep water.[1] The 15 boxes, comprising the shallow matrix, were buried in three rows of five boxes each, at depths of 3-7 m. The 15 boxes comprising the deep matrix were buried in the same 3 by 5 configuration at water depths from 12 to 16 m. Figure 7 shows the double matrix configurations of W-V boxes planted at each site. Four such double matrices of W-V boxes were established at the I-90 construction site, two on spawning overlay

----

[1] At the Beauty Bay site 24 W-V boxes were planted in two-12 box matrices (three rows of four boxes each).

Table 1. Number of Whitlock-Vibert boxes containing viable kokanee embryos planted at three sites in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, during December, 1980.

	Study Site		
Substrate Type	I-90 Construction Site	Mineral Ridge	Beauty Bay
Fractured Fill	60		
Spawning Overlay	60		
Old Fill		30	
Undisturbed			24

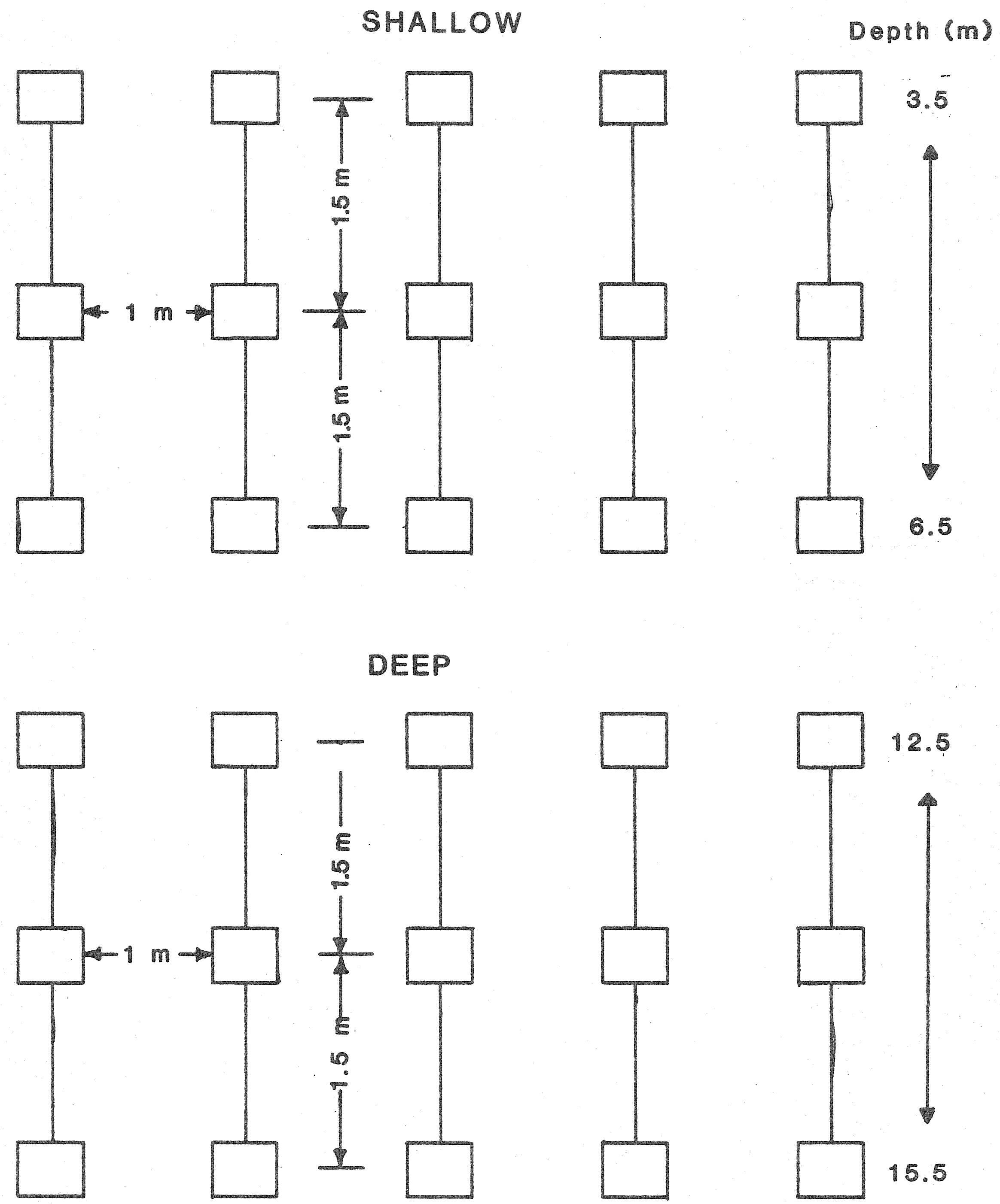

Figure 7. Embryo plants in double matrix configuration at the I-90 Construction Site and Mineral Ridge, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. At the Beauty Bay site, six rows of four boxes each were used in a similar configuration.

substrate (referenced as I-90 construction sites S01 and S02) and two on fractured fill substrate (referenced as I-90 construction sites FF1 and FF2).

After the W-V boxes were planted, all boxes were covered with 3-5 cm of substrate. For each 15 box matrix, five boxes were removed and analyzed at the eyed-egg and pre-emergent fry stages of development (total of 10 W-V boxes), and the remaining 5 boxes were used for determination of emergence success. The disposition of each box in a matrix was randomly determined.

Survival to the Eyed Egg Stage

To estimate survival to the eyed-egg stage, five boxes were removed from each 15 box matrix on 19 March, 1981. Numbers of viable and dead embryos were enumerated immediately after removal of the boxes from the water. Percent survival to the eyed egg stage was calculated based on the ratio of viable embryos to the original number of eggs placed in the box (x100).

Survival to the Pre-emergent Fry Stage

To estimate survival to the pre-emergent fry stage, five W-V boxes in each 15 box matrix were enclosed with fine mesh plastic screening at the time when they were buried in the substrate. This allowed capture of all alevins which could escape from the boxes. These boxes were removed on 19 May, 1981, and the number of alevins, viable embryos, and dead embryos enumerated immediately. All alevins were preserved in 95% ETOH for later analysis. Percent survival to the pre-emergent stage was calculated the same as survival to the eyed egg stage.

Emergence Success

Emergent fry traps were placed over 5 W-V boxes in each matrix prior to fry emergence. Traps were centered over the W-V boxes to minimize the potential for lateral movement of alevins and fry in the gravel. Substrate was placed around the base of each trap to secure its position and preclude escape of fry between the trap/substrate interface. SCUBA divers checked the traps for fry at weekly intervals beginning 4 May, 1981. All fry captured were enumerated and preserved in 95% ETOH for later analysis. Traps were removed on 30 June, 1981, at which time emergence was deemed completed based on two consecutive weeks of no fry captures.

Statistical Analyses

Survival to each life stage was compared among sites and between depths using Analysis of Variance. When significant differences were determined, Duncan's New Multiple Range Test (Ott 1977) was used for comparison of means.

Fry Quality

The condition of all emergent fry collected was determined by measuring total body length (nearest mm) and weight (nearest mg). Preserved weights were converted to live weight values using a previously determined conversion:

$$WL=WP*1.705$$

where WL = live weight and WP = preserved weight. Condition factors for all fry were calculated:

$$K=(W/(L^3))*10^5$$

where K = condition factor, W = live weight (g), and L = length (mm). Development indices, which provide an index of yolk absorption and an indication of the stage of development, also were calculated:

$$KD= (10\sqrt[3]{W})/L$$

where KD = development index, W = live weight (mg), and L = length (mm) (Bams 1970).

Substrate-Water Analysis

To relate embryo and alevin mortality to the physical environment and to assess the effects of the I-90 fill on water quality, selected water quality determinations were made periodically from the approximate initiation of spawning activity (11 November, 1980) to post-emergence (30 June, 1981). Probes were located in seven shoreline areas of Wolf Lodge Bay (Figure 8), in substrate types consisting of undisturbed areas and "old" and "new" highway fill areas. The probes consisted of 45.72 cm piezometers driven into the substrate at water depths of 1.5 and 6 m at each sampling site. Plastic tubing running from the piezometer to the surface allowed collection of water from the various sites using a vacuum pump and flask apparatus. The upper 30.48 cm of the piezometers was sealed off so water was collected from 30.48 to 45.72 cm below the water/substrate interface when samples were taken.

Substrate water analyses were conducted on 11 and 19 November, and 17 December, 1980, and 28, March, 29 May, and 30 June, 1981. Two one-liter samples were drawn from each probe on each sampling date, after a known volume of water was purged from the plastic tubing. On-site water analyses included temperature (^{o}C) and dissolved oxygen (D.O.) concentrations (mg/l) for each water sample taken at the various sites and surface D.O. and temperature. Dissolved oxygen concentrations were measured with a YSI model 57 D.O. meter. pH values of all samples were determined upon returning to the laboratory, within six hours of collection of the first sample, using a Sargent-Welch Model PBL pH meter. Also, laboratory analyses included acidity (mg/l $CaCO_3$) and alkalinity (meq/l) determinations for all samples (EPA 1974). Ferrous iron and sulfate analyses were run on selected samples on 11 and 19 November, 17 December 1980, and 28 March, 1981. Acidity and alkalinity samples were analyzed within

Figure 8. Approximate locations of substrate-water collection sites in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Each symbol (circle or square) represents one shallow and one deep piezometer.

12 hours of their arrival at the laboratory. Water samples were either refrigerated (acidity and alkalinity) or frozen (ferrous iron and sulfate) until analyses were conducted.

RESULTS

Substrate Characterization

Overall Substrate Characterization

Nearly 150 substrate samples were examined using photographic techniques to characterize spawning substrate. Substrate composition, based on median (D50) particle sizes, was different among sites (Table 2). The range of D50 particle sizes for all substrate samples was 0.19 to 210 mm. Sorting coefficients for all samples ranged from 0.19 to 3.06; this range was smaller for individual study sites which reflects the greater homogeneity of particle sizes within sites than among sites.

Substrate Utilized for Spawning

Spawning occurred on substrate over a wide range of D50 particle sizes. For all samples, the range of D50 particle sizes of substrate used for spawning was 21 to 140 mm (mean = 68 mm). The range of D50 particle sizes used for spawning was similar among sites (Table 2). The overall range of sorting coefficients of substrate used for spawning was narrow (0.25-1.90) relative to the overall range of sorting coefficients for all samples (0.19 to 3.06). Although spawning occurred over wide ranges of D50 particle sizes and sorting coefficients of substrate sampled, most spawning occurred within more restricted ranges of these values. Plotting D50 particle sizes against sorting coefficients (Fig. 9) revealed a clustering of spawning activity. From this plot, we determined most spawning (71%) occurred on substrate with D50 particle sizes ranging from 21 to 90 mm and sorting coefficients ranging from 0.5 to 1.05.

Table 2. Substrate characterization of spawned and unspawned samples using photographic techniques at study sites in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho.

Site	n	D 16			D 50			D 84			Sorting Coefficient		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Beauty Bay													
Spawned	4	6	13	1	35	38	32	66	99	54	1.28	2.00	0.62
Unspawned	5	5	27	0.05	19	70	0.19	66	145	1	2.00	3.06	0.73
I-90 Construction Site													
Spawned	6	17	32	2	56	70	30	105	146	54	0.89	1.86	0.52
Unspawned	30	50	152	0.30	115	205	38	167	257	69	0.77	2.36	0.20
I-90 West													
Spawned	11	28	77	8	68	115	21	114	194	51	0.69	0.94	0.27
Unspawned	16	168	134	1	149	190	90	205	238	124	0.83	2.35	0.23
Mineral Ridge													
Spawned	11	20	41	2	78	140	28	145	242	53	0.93	2.02	0.54
Unspawned	18	46	159	0.14	102	210	4	171	249	70	1.11	2.77	0.19
All Sites													
Spawned	32	21	77	1	65	140	21	117	242	51	0.88	2.02	0.27
Unspawned	69	50	159	0.05	113	210	0.19	170	257	1	0.96	3.06	0.19

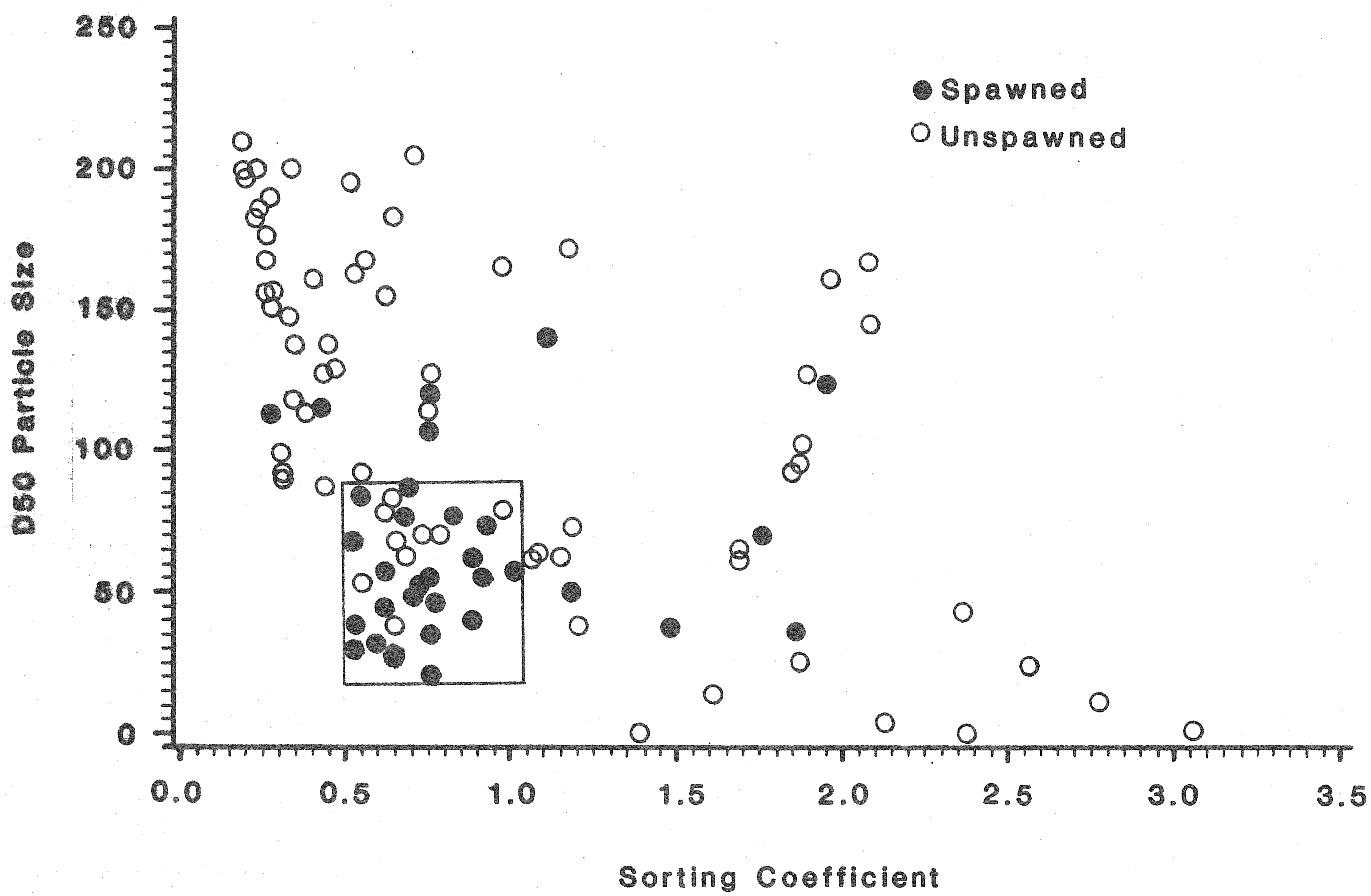

Figure 9. Substrate characterization based on fiftieth percentiles (D50) and sorting coefficients determined at the I-90 Construction site, Beauty Bay, I-90 West, and Mineral Ridge study areas, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. The rectangle represents "preferred" spawning substrate for all sites combined. Substrate characterization was made using photographic techniques.

Preferred Substrate

Based on the predominance of spawning activity within a restricted range of D50 particle sizes (21-90mm) and sorting coefficients (0.5-1.05), substrate satisfying these criteria was classified as "preferred" for kokanee spawning (Fig. 9). Superimposing these criteria on substrate at each site indicated the availability of preferred spawning substrate (% of total area, Table 3) as: I-90 West - 29% (Fig. 10); Beauty Bay - 23% (Fig. 11); Mineral Ridge - 26% (Fig. 12); and, I-90 Construction Site fractured fill - 31% (Fig. 13). Since all of the spawning overlay material was within the preferred range of particle sizes, 61% of the total I-90 Construction Site was considered preferred spawning substrate.

Unique characteristics of substrate used for spawning is typically that with low to moderate D50 and D84 values and low sorting coefficients (approximately less than 1.0). This is clearly demonstrated by 3-dimensional representation at I-90 West (Fig. 14), Beauty Bay (Fig. 15), Mineral Ridge (Fig. 16), and I-90 Construction site fractured fill (Fig. 17) areas.

Extent of Spawning Utilization

Total utilization of substrate for kokanee spawning at each study site was estimated by capturing fry in randomly placed emergent fry traps and the presence of kokanee embryos at the transects. Percent utilization of substrate, as determined from emergent fry traps, was: I-90 construction site spawning overlay - 100%; I-90 construction site fractured fill - 100%; and, Mineral Ridge - 100%. Although fry were caught in all emergence traps, numbers of fry caught per trap and total number of fry caught from each site were variable (Table 4). Higher numbers of fry per trap were caught on the I-90 construction sites (1-51), whereas, captures at Mineral Ridge were low (range = 1-10 fry/trap). However, percentages of substrate utilized (percent of total

Table 3. Availability and utilization of "preferred" spawning substrate at six locations in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho.

	Within Preferred[a] Range		Outside of Preferred Range		
	Percent of Total Substrate	Percent Spawned	Percent of Total Substrate	Percent Spawned	Percent of Total Substrate Spawned
I-90 West	29	100	71	15	39
Beauty Bay	23	67	77	10	23
Mineral Ridge	26	78	74	16	32
I-90 Construction Site					
Fractured Fill	31	45	69	4	17
Spawning Overlay	100	33	0	-	33
Combined	61	36	39	10	
All Sites Combined	28	71	72	11	28

[a] D50 21-90 mm with sorting coefficient of 0.50 - 1.05.

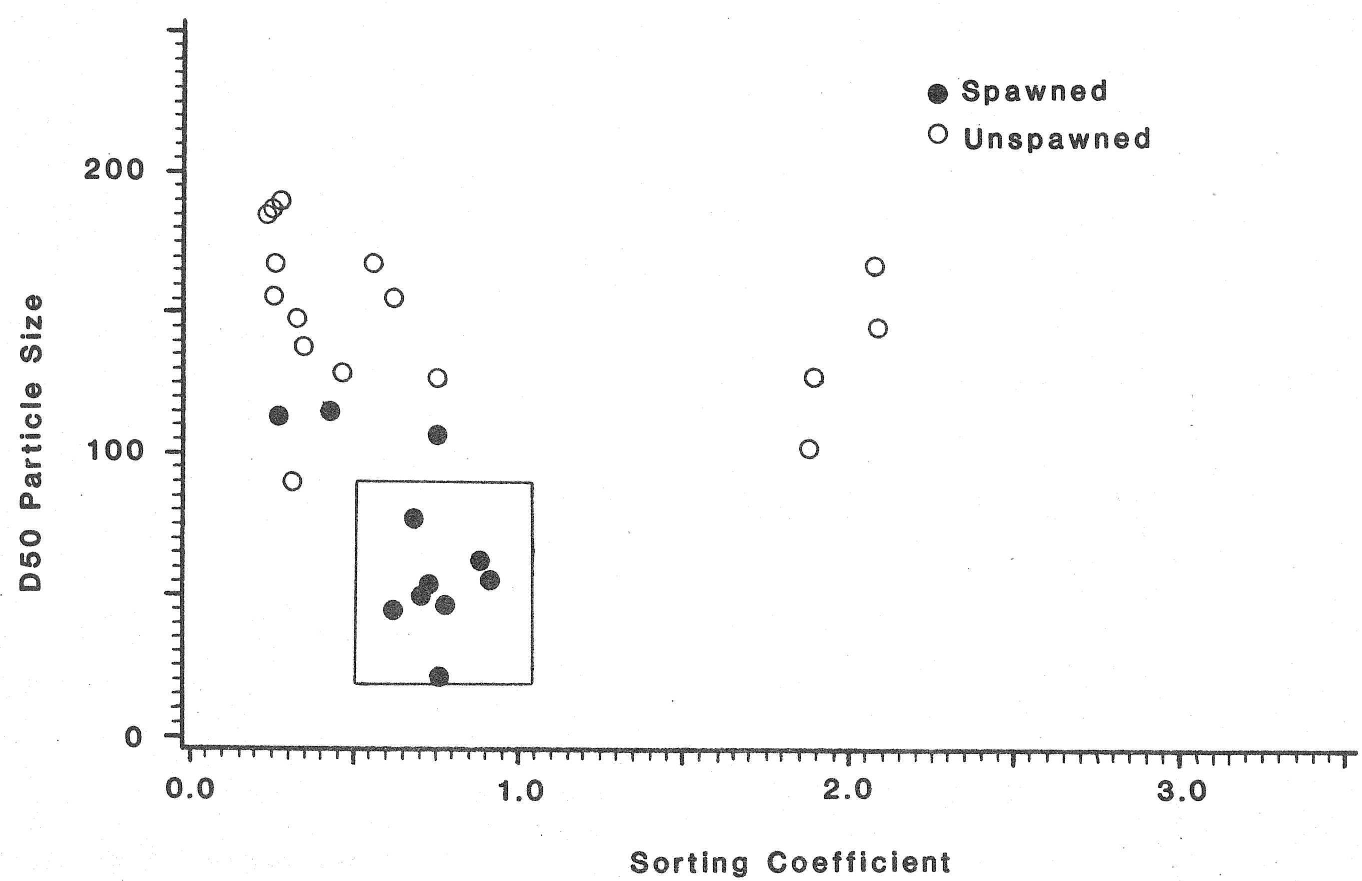

Figure 10. Substrate characterization based on fiftieth percentiles (D50) and sorting coefficients determined at the I-90 West study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. The rectangle represents "preferred" spawning substrate. Substrate characterization was made using photographic techniques.

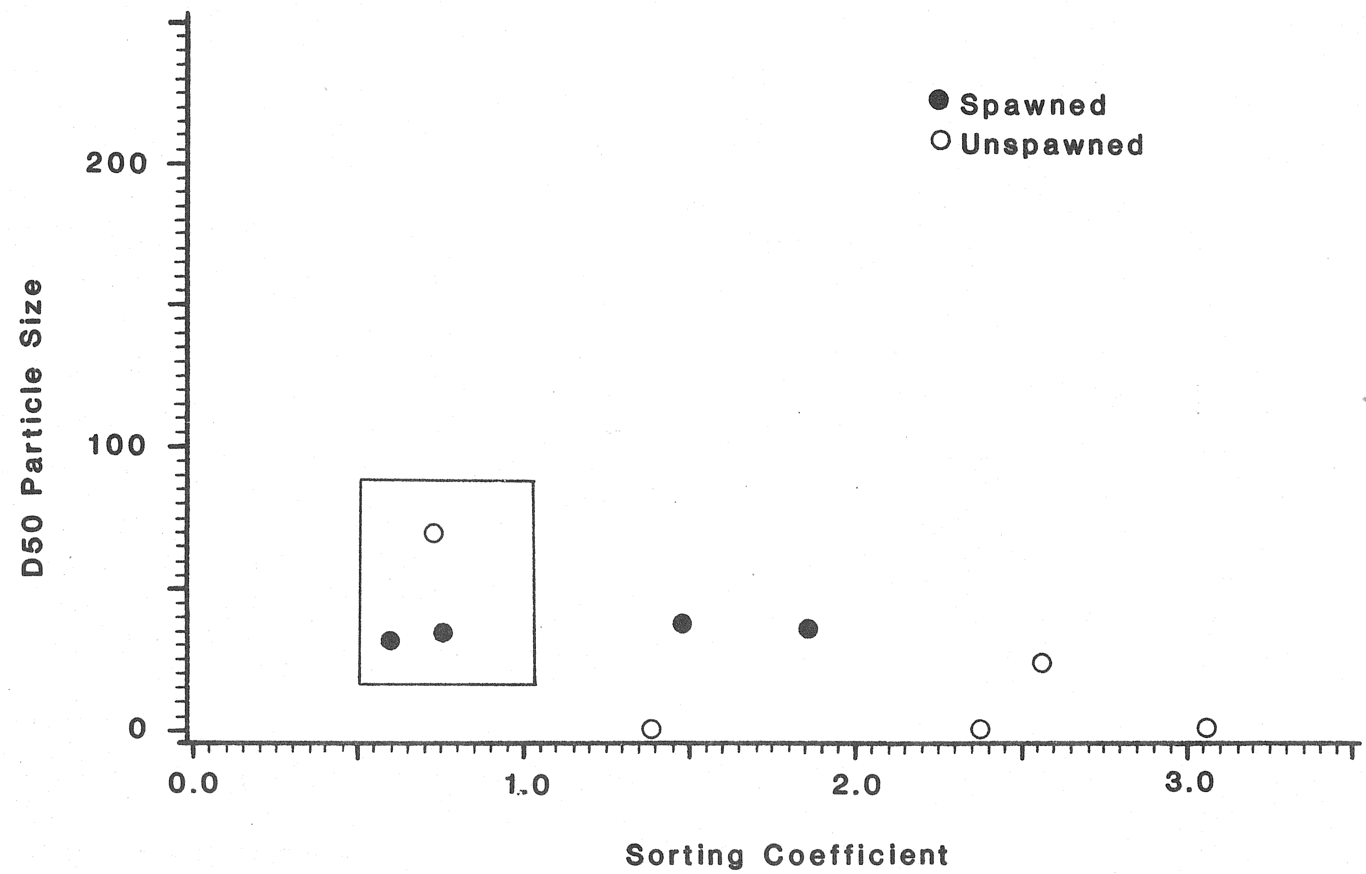

Figure 11. Substrate characterization based on fiftieth percentiles (D50) and sorting coefficients determined at the Beauty Bay study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. The rectangle represents "preferred" spawning substrate. Substrate characterization was made using photographic techniques.

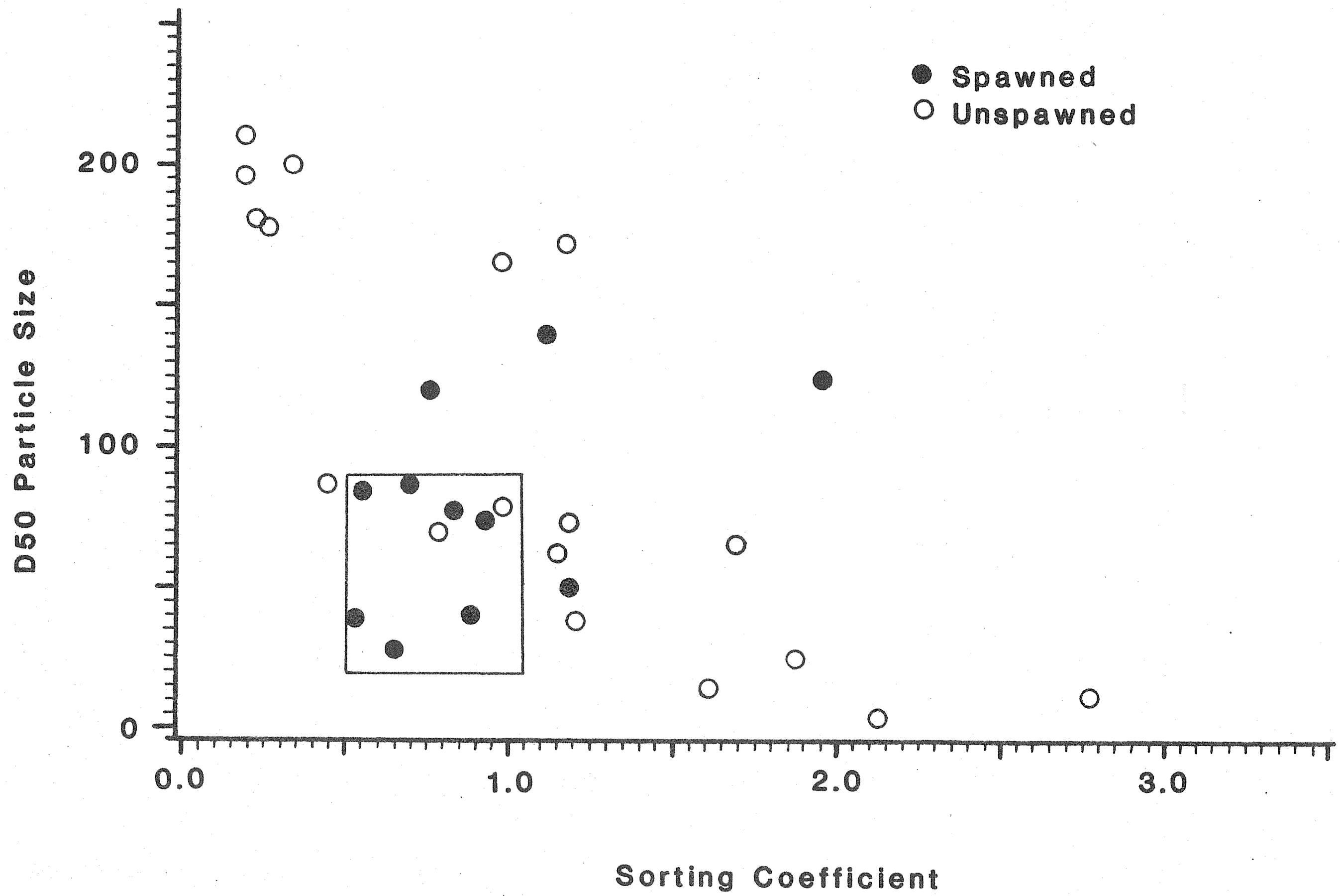

Figure 12. Substrate characterization based on fiftieth percentiles (D50) and sorting coefficients determined at the Mineral Ridge study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. The rectangle represents "preferred" spawning substrate. Substrate characterization was made using photographic techniques.

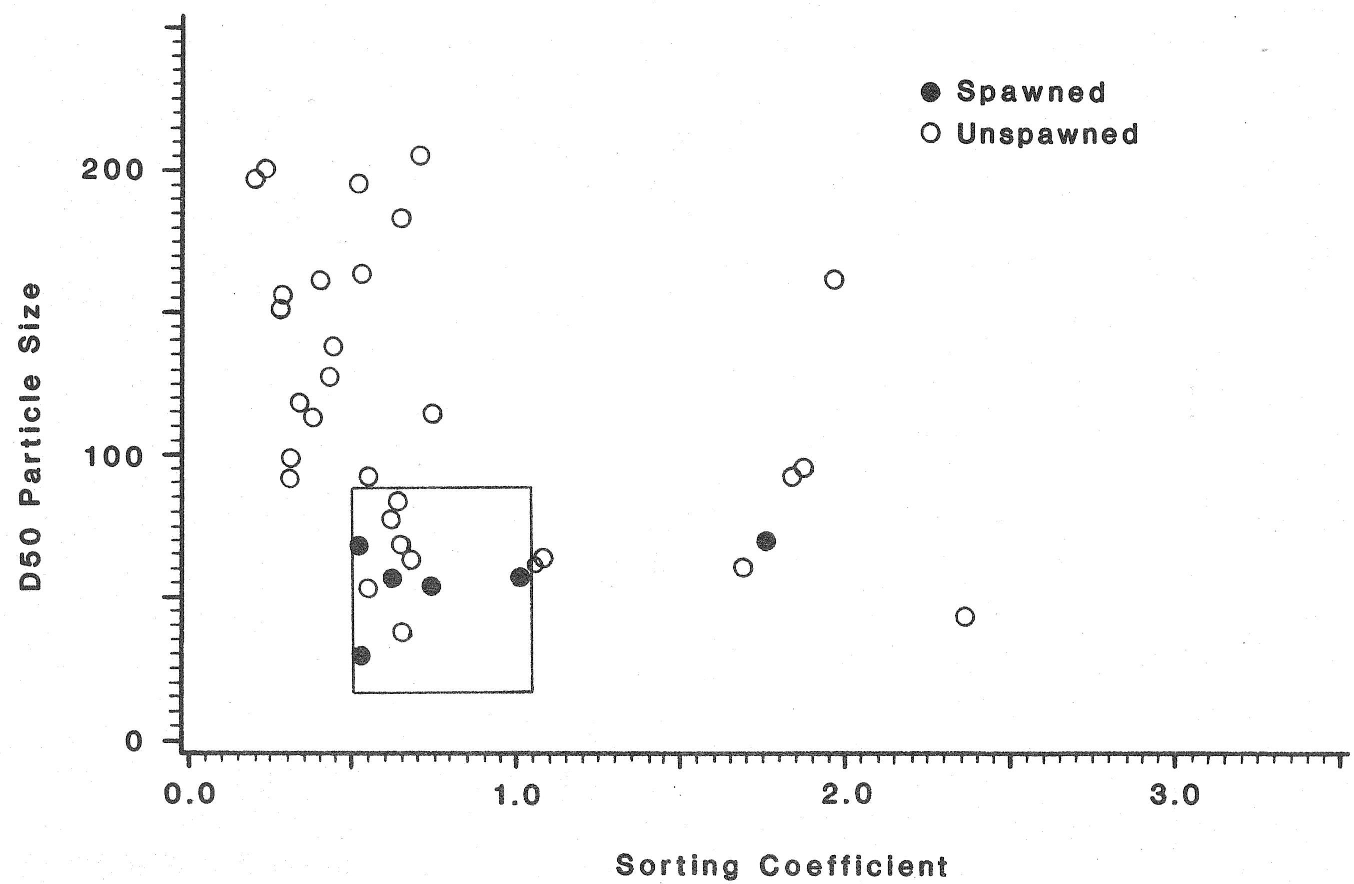

Figure 13. Substrate characterization based on fiftieth percentiles (D50) and sorting coefficients determined at the I-90 Construction Site (fractured fill), Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. The rectangle represents "preferred" spawning substrate. Substrate characterization was made using photographic techniques.

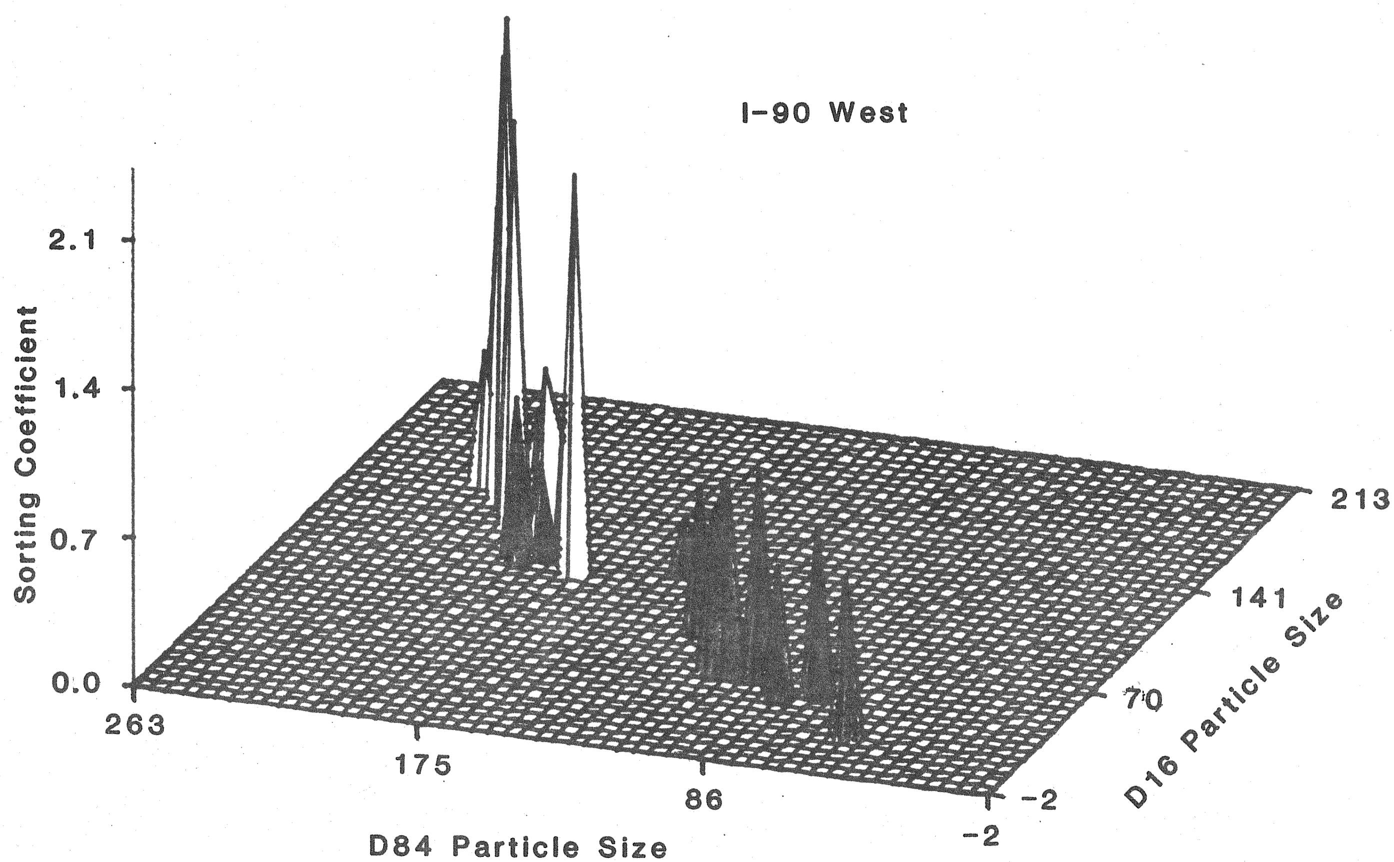

Figure 14. Three dimensional representation of substrate sampled at the I-90 West study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Each spike represents one photograph; shaded spikes represent substrate utilized for kokanee spawning.

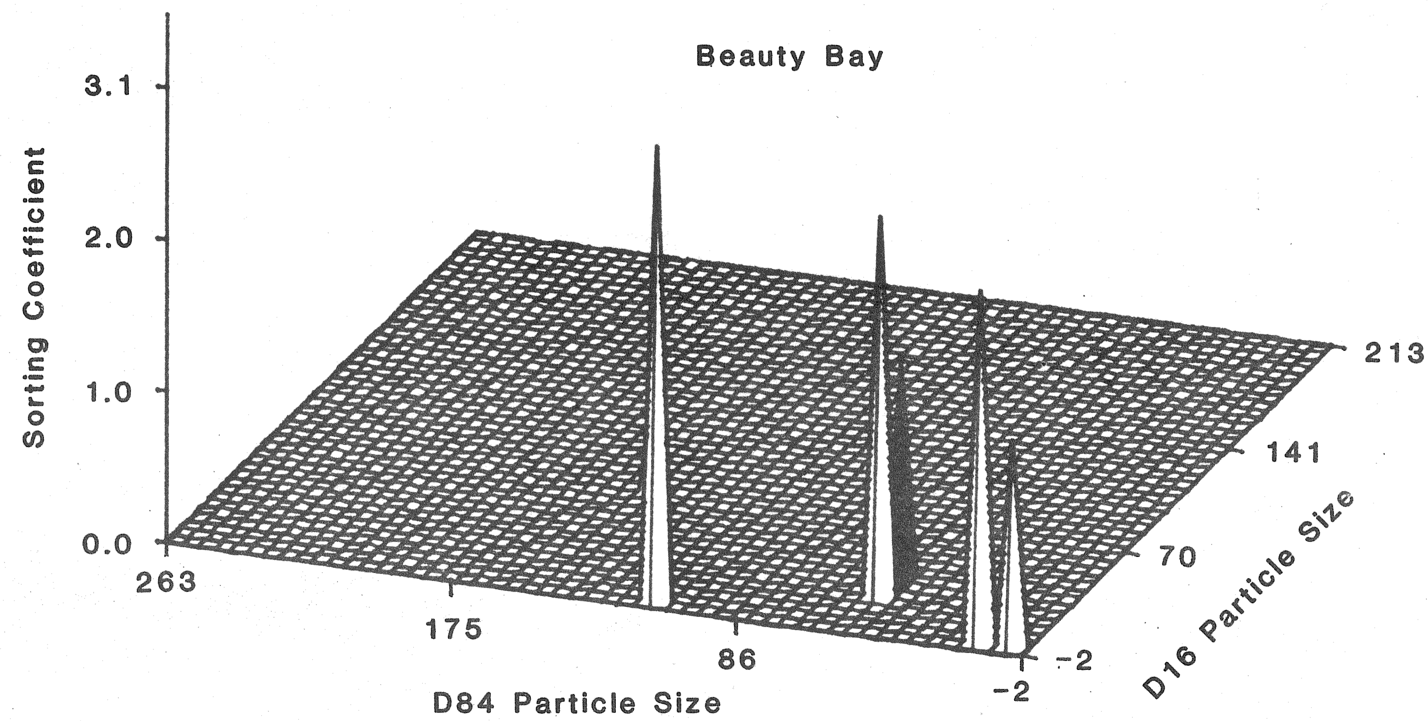

Figure 15. Three dimensional representation of substrate sampled at the Beauty Bay study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Each spike represents one photograph; shaded spikes represent substrate utilized for kokanee spawning.

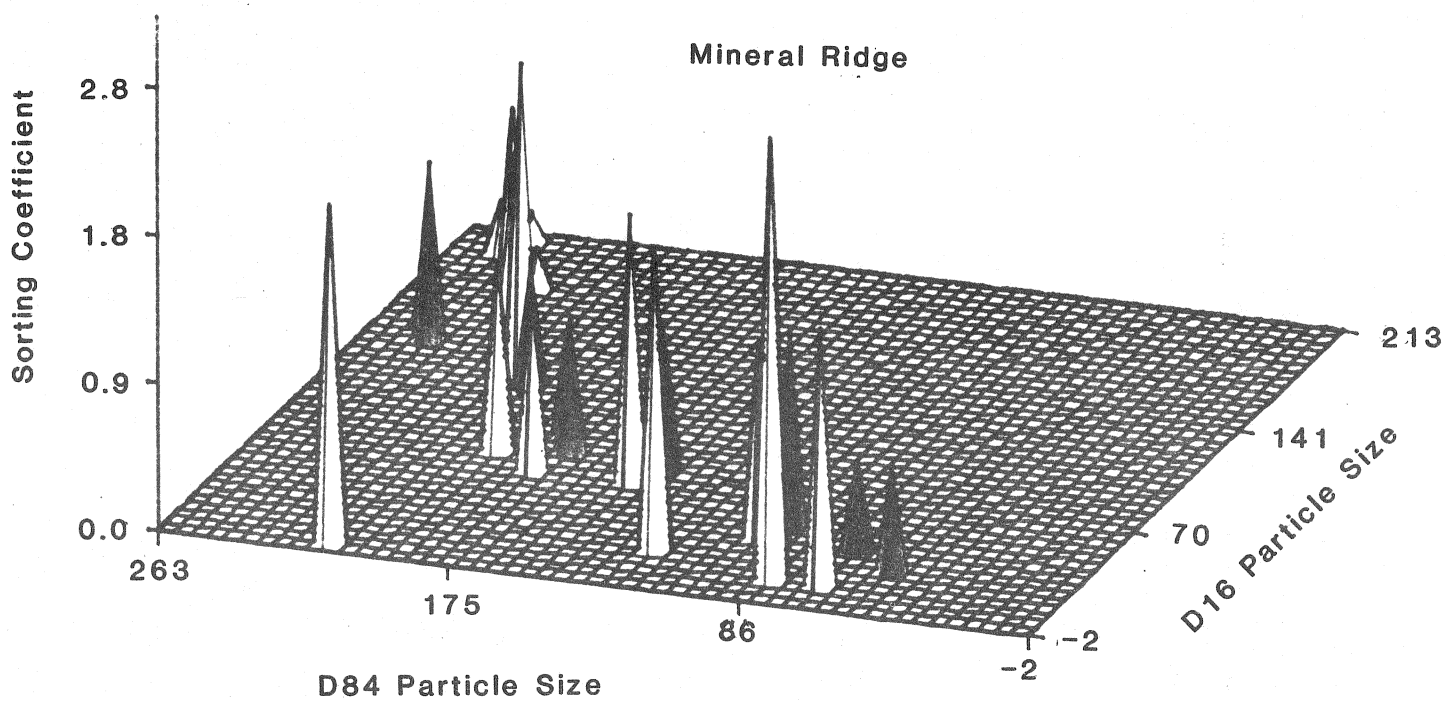

Figure 16. Three dimensional representation of substrate sampled at the Mineral Ridge study site, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Each spike represents one photograph; shaded spikes represent substrate utilized for kokanee spawning.

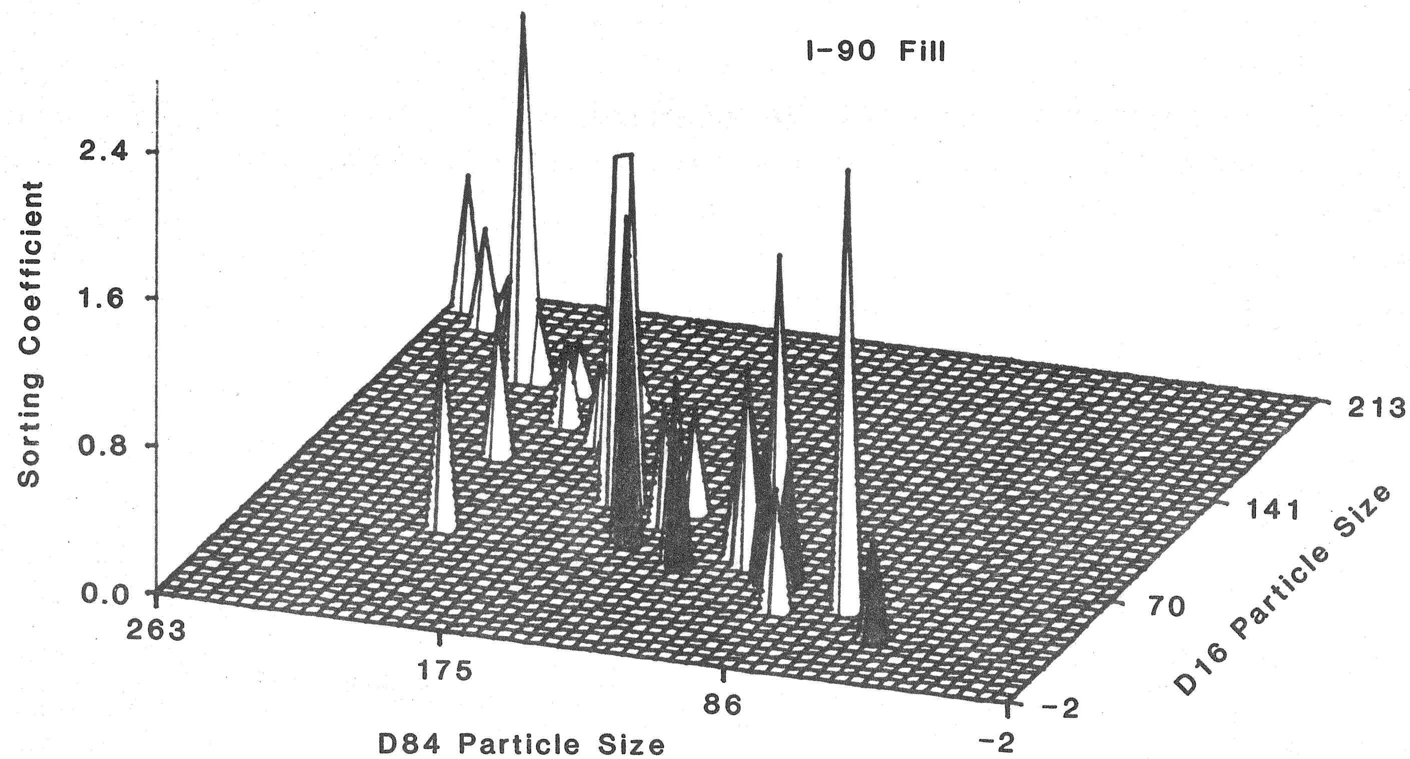

Figure 17. Three dimensional representation of substrate sampled at the I-90 Construction site (fractured fill), Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Each spike represents one photograph; shaded spikes represent substrate utilized for kokanee spawning.

Table 4. Kokanee fry captures from emergent fry traps placed randomly on I-90 construction site spawning overlay and fractured fill and Mineral Ridge substrates, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho.

	Study Area		
	I-90 Construction Site		
Trap	Spawning Overlay	Fractured Fill	Mineral Ridge[a]
1	24	45	2
2	1	15	2
3	41	16	1
4	31	17	3
5	20	20	2
6	17	12	10
7	21	30	7
8	13	10	2
9	39	14	3
10	11	13	
11	24	18	
12	24	6	
13	43	12	
14	5	4	
15	51	13	
$\overline{X}$ fry/trap	24.3	16.3	3.6
Total fry	365	245	32

[a] 9 traps used

substrate area sampled) as determined from the SCUBA transects were considerably lower. Estimates of the extent of substrate utilization for spawning, based on transects, were: I-90 construction site spawning overlay - 33.5% fractured fill - 12.5%; Mineral Ridge - 36.3%; Beauty Bay - 41.2%; and, I-90 West - 34.5%.

Extent of utilization of substrate classified as preferred, based on verified embryo deposition, was high at all study areas except the I-90 construction site substrates (Table 3). Percent utilization of preferred spawning substrate at the I-90 construction site was 45% and 33% for fractured fill and spawning overlay, respectively. At the remaining sites, percent utilization of preferred spawning substrate ranged from 67% to 100%. Utilization of substrate not within the preferred range at all sites was low (maximum = 15%).

Embryo Survival

Eyed Egg Stage

Survival of planted embryos to the eyed egg stage was high at all sites except Beauty Bay (Table 5). Survival was not significantly different among I-90 Construction Sites (SO1, SO2, FF1, FF2) and Mineral Ridge but was significantly lower at Beauty Bay than any of the other sites. No significant difference in survival to the eyed egg stage was found between shallow (76.4%) and deep (72.3%) planted embryos for all sites ($F=1.41$; $P=0.24$).

Pre-emergent Fry Stage

Although highly variable within planting sites (one planting site = one shallow and one deep W-V box matrix), survival to the pre-emergent fry stage was high except at the Beauty Bay site (Table 5). Mean survival of pre-emergent fry was significantly lower at Beauty Bay than at all other sites. Mean survival at Mineral Ridge (38.1%) was not significantly different than at I-90 Construction Site spawning overlay (24.8%; SO1 and SO2) and fractured fill substrate area sampled) as determined from the SCUBA transects were considerably lower. Estimates of the extent of substrate utilization for spawning, based on transects, were: I-90 construction site spawning overlay - 33.5% fractured fill - 12.5%; Mineral Ridge - 36.3%; Beauty Bay - 41.2%; and, I-90 West - 34.5%.

Extent of utilization of substrate classified as preferred, based on verified embryo deposition, was high at all study areas except the I-90 construction site substrates (Table 3). Percent utilization of preferred spawning substrate at the I-90 construction site was 45% and 33% for fractured fill and spawning overlay, respectively. At the remaining sites, percent utilization of preferred spawning substrate ranged from 67% to 100%. Utilization of substrate not within the preferred range at all sites was low (maximum = 15%).

Embryo Survival

Eyed Egg Stage

Survival of planted embryos to the eyed egg stage was high at all sites except Beauty Bay (Table 5). Survival was not significantly different among I-90 Construction Sites (SO1, SO2, FF1, FF2) and Mineral Ridge but was significantly lower at Beauty Bay than any of the other sites. No significant difference in survival to the eyed egg stage was found between shallow (76.4%) and deep (72.3%) planted embryos for all sites ($F=1.41$; $P=0.24$).

Pre-emergent Fry Stage

Although highly variable within planting sites (one planting site = one shallow and one deep W-V box matrix), survival to the pre-emergent fry stage was high except at the Beauty Bay site (Table 5). Mean survival of pre-emergent fry was significantly lower at Beauty Bay than at all other sites. Mean survival at Mineral Ridge (38.1%) was not significantly different than at I-90 Construction Site spawning overlay (24.8%; SO1 and SO2) and fractured fill

Table 5. Mean survival rates (%) to eyed-egg, pre-emergent fry and emergent fry stages of planted kokanee embryos at six locations in Wolf Lodge Bay, Coeur d'Alene, Idaho, 1981. Sample sizes also indicated ( ).

Site	Eyed Egg		Pre-Emergent Fry		Emergent Fry	
I-90 Construction Site [a]						
FF1						
Shallow	86.6	(5)	61.4	(5)	3.8	(5)
Deep	89.0	(5)	36.7	(3)	10.0	(5)
Combined	87.8	(10)	52.1	(8)	6.9	(10)
SO1						
Shallow	88.2	(5)	30.5	(4)	25.0	(4)
Deep	83.8	(5)	18.2	(5)	49.0	(5)
Combined	86.0	(10)	23.7	(9)	38.3	(9)
FF2						
Shallow	76.2	(5)	62.6	(5)	25.8	(5)
Deep	85.2	(5)	54.3	(3)	7.2	(5)
Combined	80.7	(10)	59.5	(8)	16.5	(10)
SO2						
Shallow	84.3	(4)	30.6	(5)	43.3	(4)
Deep	81.2	(5)	20.0	(4)	62.5	(4)
Combined	82.6	(9)	25.9	(9)	52.9	(8)
Mineral Ridge						
Shallow	88.6	(5)	47.2	(5)	1.8	(4)
Deep	74.0	(3)	26.8	(4)	1.5	(4)
Combined	83.1	(8)	38.1	(9)	1.6	(8)
Beauty Bay						
Shallow	11.3	(4)	1.0	(3)	0.0	(4)
Deep	5.0	(4)	2.8	(4)	0.0	(4)
Combined	8.1	(8)	2.0	(7)	0.0	(8)

Column group heading: Development Stage (over Eyed Egg, Pre-Emergent Fry, Emergent Fry)

[a] FF = fractured fill
SO = spawning overlay

(55.8%; FF1 and FF2) substrates, although pre-emergent fry survival was significantly lower at the spawning overlay sites (24.8%) than at the fractured fill (55.8%) sites (Table 5).

Mean survival to the pre-emergent fry stage was significantly lower at deep water sites than at shallow water sites (F=3.96; P=0.054). Mean survival rates for shallow and deep planted embryos were 39.4% and 19.8%, respectively.

Emergence Success

Catches of fry in emergent fry traps from planted embryos, although extremely variable within sites, were highest at the I-90 construction site. Emergent fry trap captures of fry at Mineral Ridge were only slightly higher than at Beauty Bay. Based on emergent fry trap captures, emergence success ranged from 0% (Beauty Bay, shallow and deep traps combined) to 60% (I-90 Construction site-S02, shallow and deep traps combined) at the various sites (Table 5).

The temporal distribution of emergence also was determined from emergent fry trap catches. Based on emergent fry trap catches, emergence began 4 May and was completed by 17 June. Patterns of the temporal distribution of emergence were not different among study sites (Figs. 18-20), shallow and deep planted kokanee embryos (Fig. 21), and planted and naturally deposited embryos (Fig. 22).

Fry Quality

Length

The range of mean lengths at emergence was 22 to 23 mm (Table 6). Mean length at emergence was not significantly different between planted and naturally deposited embryos (F=3.01; P=0.134). Comparison of mean lengths at emergence for planted embryos revealed no significant differences among

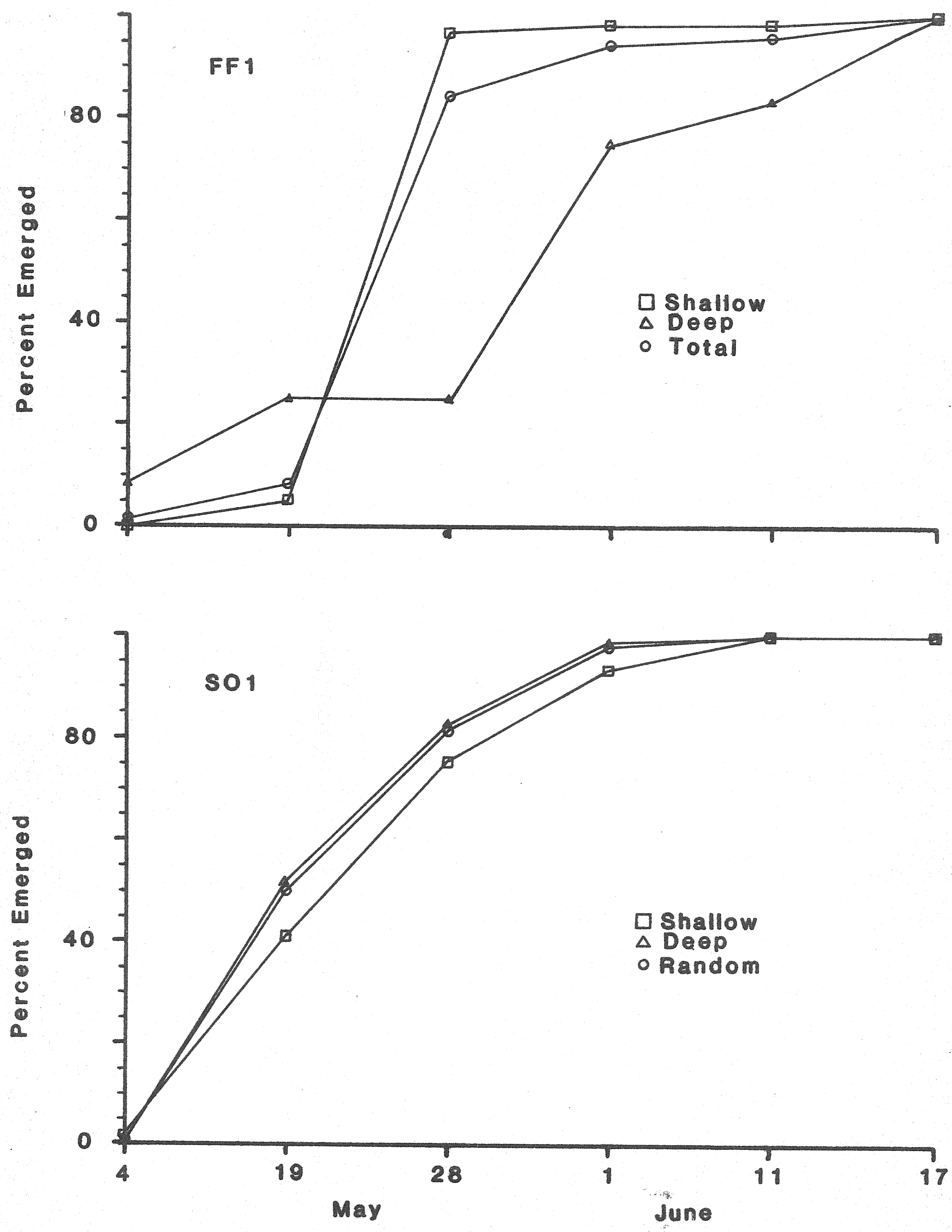

Figure 18. Cumulative percent emergence of kokanee fry from shallow and deep W-V boxes at I-90 Construction Sites with fractured fill (FF1) and spawning overlay (SO1) based on emergent fry trap catches from May through June, 1981, Coeur d'Alene Lake, Idaho.

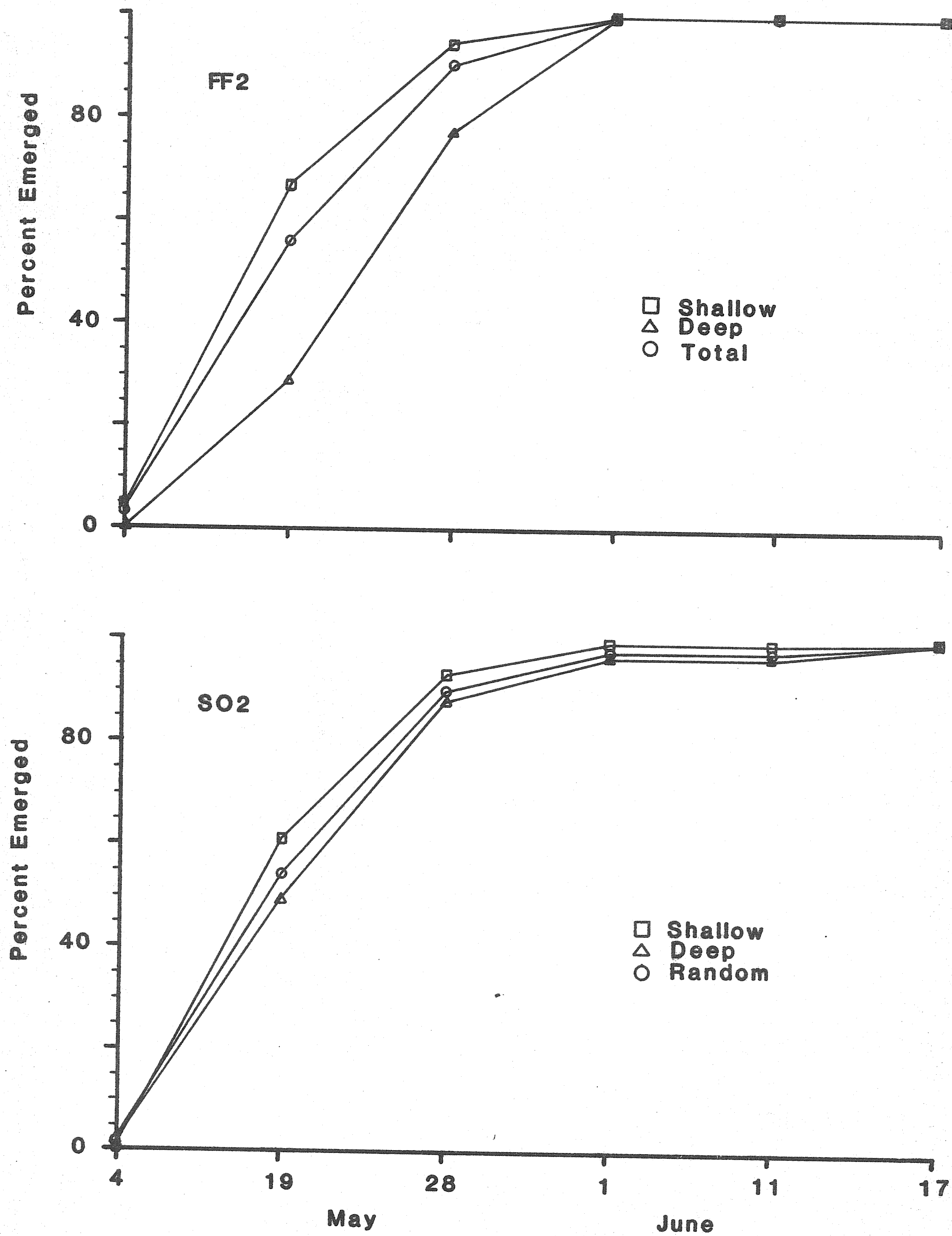

Figure 19. Cumulative percent emergence of kokanee fry from shallow and deep W-V boxes at I-90 Construction Sites with fractured fill (FF2) and spawning overlay (SO2) based on emergent fry trap catches from May through June, 1981, Coeur d'Alene Lake, Idaho.

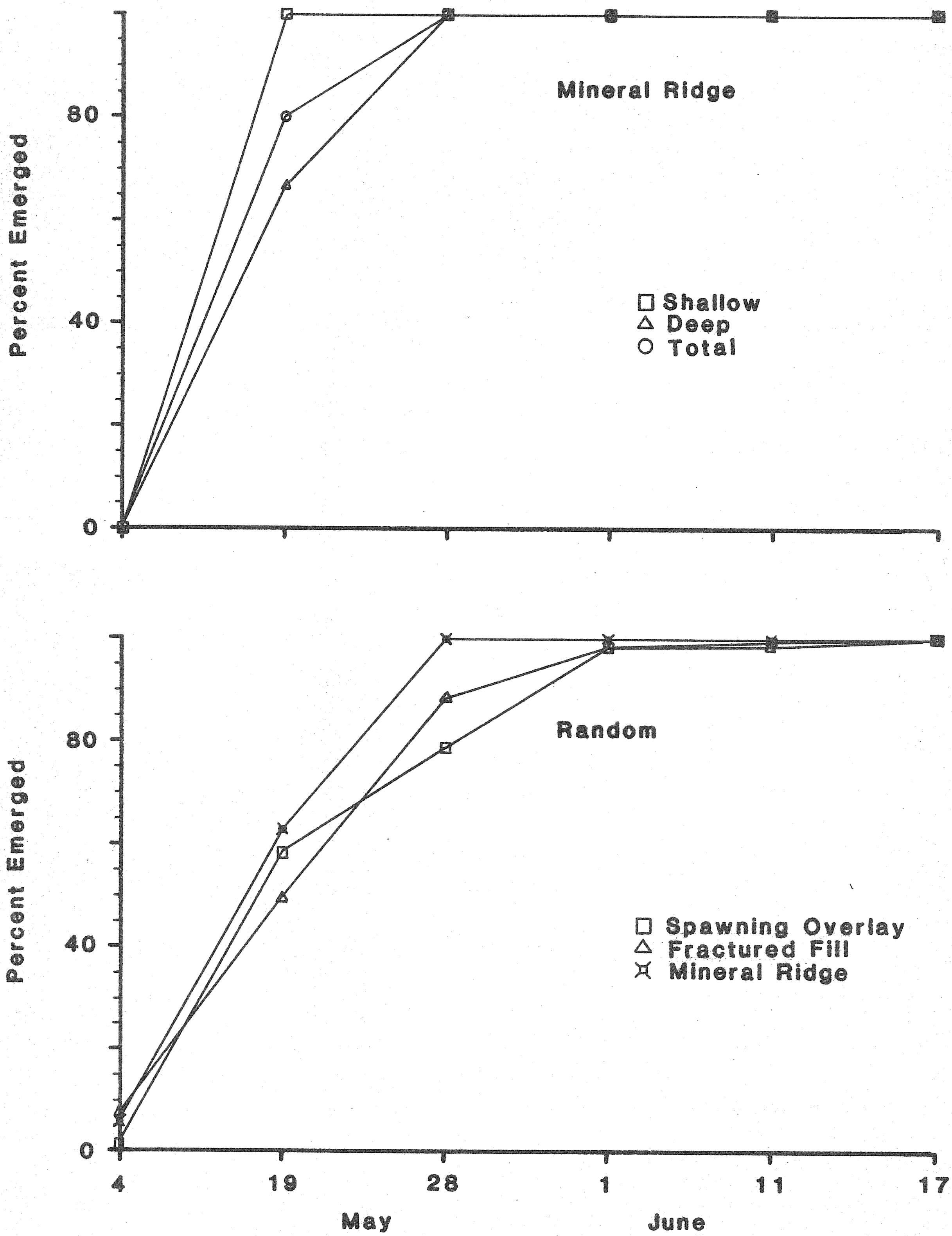

Figure 20. Cumulative percent emergence of kokanee fry based on emergent fry trap catches from shallow and deep W-V boxes at Mineral Ridge and randomly placed traps on fractured fill, spawning overlay, and Mineral Ridge from May through June, 1981, Coeur d'Alene Lake, Idaho.

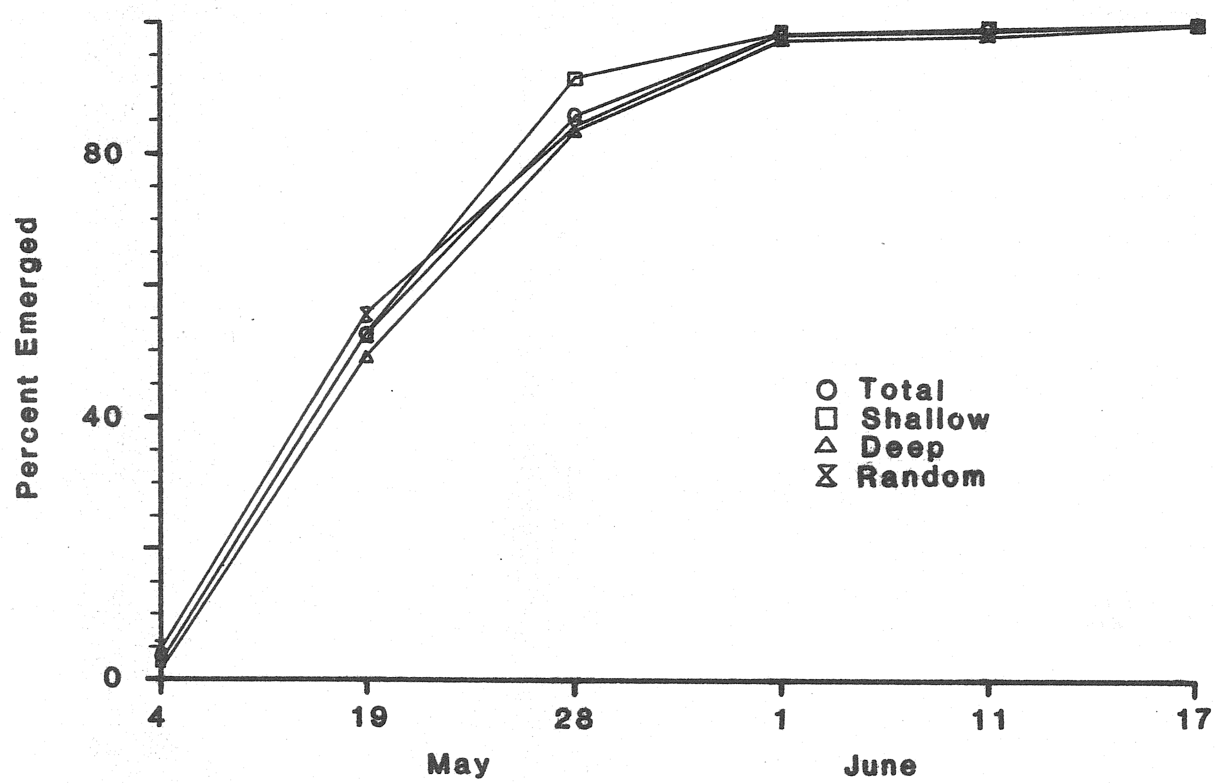

Figure 21. Cumulative percent emergence of kokanee fry based on emergent fry trap catches from May through June, 1981, Coeur d'Alene Lake, Idaho.

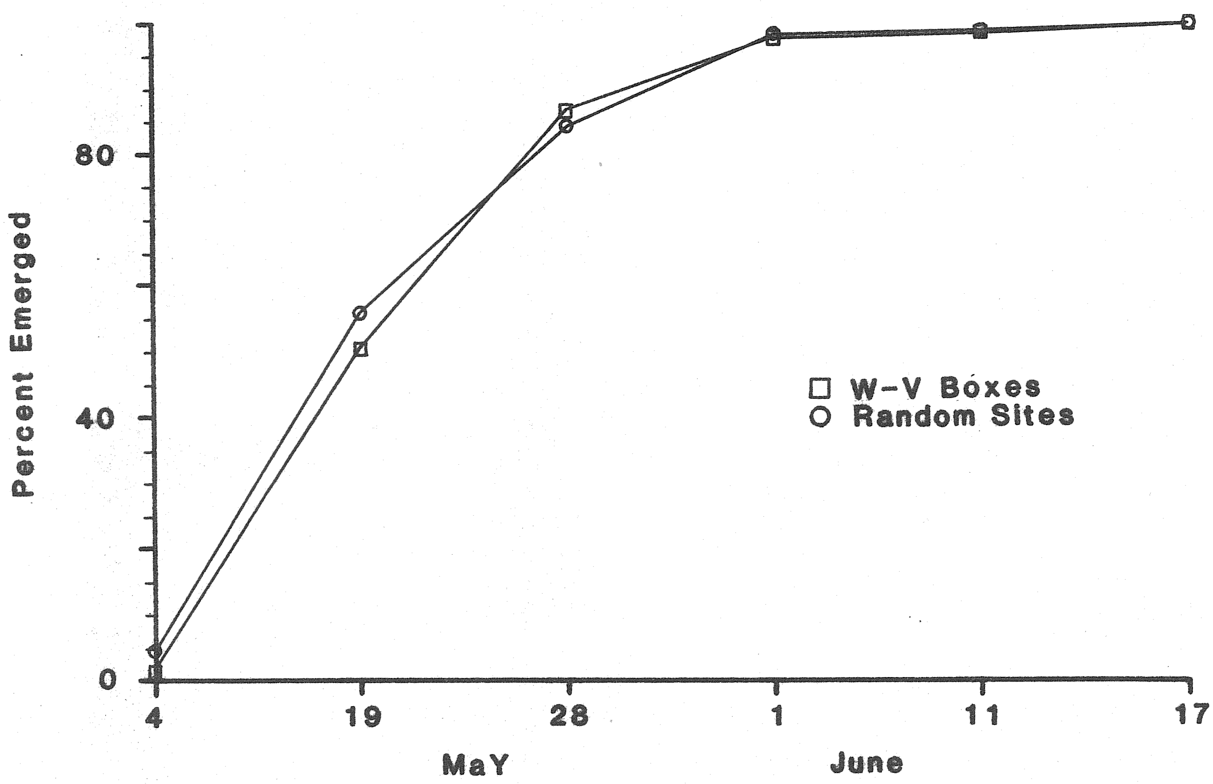

Figure 22. Cumulative percent emergence of kokanee fry from planted (Whitlock-Vibert (W-V) Boxes) and naturally spawned embryos, based on emergent fry trap catches from May through June, 1981, Coeur d'Alene Lake, Idaho.

Table 6. Overall comparison of kokanee fry quality based on date, site and depth of collection in emergent fry traps, Coeur d'Alene Lake, Idaho. Number of fry measured are shown ( ). K factor (weight x 10^5/Length^3) and development index ((10 $\sqrt[3]{\text{weight}}$)/length) were calculated from live weight measurements.

Comparison	Length (mm)	Weight (g)	Kfactor	Development Index
Date				
04 May	23.7 (22)	0.09 (22)	0.68	1.89
19 May	22.6 (857)	0.06 (854)	0.52	1.73
28 May	21.7 (581)	0.05 (569)	0.46	1.66
01 Jun.	22.1 (152)	0.06 (151)	0.50	1.71
11 Jun.	22.4 (13)	0.06 (13)	0.47	1.67
17 Jun.	22.8 (19)	0.06 (19)	0.49	1.69
Site				
I-90 Construction Sites[a]				
FF1	21.8 (64)	0.05 (64)	0.45	1.65
FF2	22.4 (132)	0.06 (132)	0.49	1.69
SO1	22.0 (351)	0.05 (345)	0.49	1.70
SO2	22.2 (392)	0.05 (387)	0.49	1.70
FF Random	22.2 (290)	0.05 (287)	0.49	1.69
SO Random	22.5 (374)	0.06 (372)	0.54	1.75
Mineral Ridge	22.0 (8)	0.06 (8)	0.52	1.73
Mineral Ridge Random	22.9 (33)	0.06 (33)	0.49	1.70
Depth				
Shallow	22.1 (392)	0.05 (391)	0.48	1.68
Deep	22.1 (555)	0.05 (545)	0.49	1.70
Random	22.4 (697)	0.06 (692)	0.52	1.72

[a] FF = fractured fill
SO = spawning overlay

sites (F=1.58; P=0.177). Differences in mean length at emergence among dates were significant for planted embryos (F=7.21; P=0.0001). Mean length of fry decreased after the initial collection date (4 May) through 28 May and increased thereafter.

Weight

Mean weight at the initiation of emergence was approximately 0.09 grams. Mean weights of fry from planted and naturally deposited embryos were not significantly different (F=4.91; P=0.069). For planted embryos only, differences in mean weight at emergence were not significant among sites (F=1.20; P=0.310), but were significant among dates (F=12.92; P=0.0001). Mean weight of fry at emergence decreased with time after the first collection of fry (Table 6).

Condition Factor

Emerging fry decreased in average condition factor from the inception to the completion of emergence (Table 6). Mean condition factors of emergent fry from planted and naturally deposited embryos were not significantly different (F=3.08; P=0.316), but differences among dates were significant (F=6.29; P=0.0001).

Development Index

Stage of development of emerging fry was similar among sites and type of embryo plant (Table 6). No significant difference in stage of development was found between fry of planted and naturally deposited embryos (F=3.22; P=0.123). Stage of development of fry from planted embryos was not significantly different among sites (F=1.27; P=0.282), but was significantly different among dates of collection (F=6.74; P=0.0001).

Mean development index at the initiation of emergence (4 May) was 1.893, but decreased through May (1.66). After 1 June, the development index of collected fry declined slightly (Table 6).

Substrate Water Analysis

Water quality parameters monitored during the study were similar among sites but differed with date. As expected, mean surface D.O. and temperature determinations were similar among study sites (Table 7). Mean temperatures of substrate water samples, classified by site, date, and depth, are listed in Table 8.

Mean pH of interstitial water ranged from 6.7 to 6.9; the minimum pH was 6.4 on 29 May 1981. Mean pH values classified by site, date, and depth are listed in Table 9 and are compared graphically among sites in Figure 23. No significant difference in pH was found among sites (F=2.07; P=0.199), but significant differences were found among dates (F=96.78; P=0.0001). Also, differences in pH between depths were significant (F=4.53; P=0.077).

Interstitial dissolved oxygen levels were generally at or near saturation and mean levels did not fall below 6.8 mg/l. Mean D.O. concentrations are classified by site, date, and depth in Table 10 and are compared graphically among sites in Figure 24. Dissolved oxygen concentrations were not significantly different among sites (F=1.21; P=0.411) or between depths (F=0.21; P=0.661). However, differences in D.O. were significant (F=9.74; P=0.0002) among dates.

Alkalinity levels were low at all collection sites for all sampling dates (0.27-0.66 meq/l). Mean alkalinity levels are classified by site, date, and depth in Table 11 and are compared graphically among sites in Figure 25. No significant difference in alkalinity was detected among sites (F=1.53; P=0.31) or between depths (F=3.53; P=0.109).

Acidity levels also were low at all collection sites for all sampling dates (0-53 mg/l $CaCO_3$). Mean acidity levels are classified by site, date, and depth in Table 12 and are compared graphically among sites in Figure 26. No significant difference in acidity was detected between depths (F=1.96; P=0.211).

Table 7. Mean surface temperature and dissolved oxygen concentration (D.O.) on dates of collection of substrate water samples, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Sample sizes also are indicated ( ).

DATE	TEMPERATURE (^{o}C)	D.O. (mg/1)
11 Nov. 1980	10.6 (3)	11.9 (3)
19 Nov. 1980	7.1 (4)	11.8 (4)
17 Dec. 1980	4.3 (5)	11.7 (4)
20 Mar. 1981	4.7 (5)	12.5 (5)
29 May 1981	15.3 (4)	9.4 (4)
30 Jun. 1981	15.6 (6)	9.1 (6)

Table 8. Mean temperatures (^{o}C) from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date						Mean
		1980			1981			
		11 Nov.	19 Nov.	17 Dec.	20 Mar.	29 May	30 June	
I-90 Construction Site [a]								
F1	Shallow	-	7.1 (2)	5.0 (2)	5.7 (2)	15.8 (2)	17.5 (2)	10.2 (10)
	Deep	-	7.1 (2)	4.3 (2)	5.7 (2)	16.1 (2)	16.9 (2)	10.0 (10)
	Combined	-	7.1 (4)	4.6 (4)	5.7 (4)	15.9 (4)	17.2 (4)	10.1 (20)
F2	Shallow	-	7.3 (2)	4.7 (2)	6.5 (2)	15.3 (2)	16.0 (2)	9.9 (10)
	Deep	-	7.1 (2)	4.4 (2)	6.9 (2)	14.9 (2)	15.5 (2)	9.7 (10)
	Combined	-	7.2 (4)	4.5 (4)	6.7 (4)	15.1 (4)	15.8 (4)	9.8 (20)
F3	Shallow	-	7.3 (2)	4.1 (2)	-	-	16.1 (2)	9.2 (6)
	Deep	-	7.2 (2)	4.4 (2)	7.1 (2)	14.3 (2)	14.5 (2)	9.5 (10)
	Combined	-	7.2 (4)	4.3 (4)	7.1 (2)	14.3 (2)	15.3 (4)	9.4 (16)
F4	Shallow	-	-	4.2 (2)	7.7 (2)	15.4 (2)	16.3 (2)	10.9 (8)
	Deep	-	6.9 (2)	4.2 (2)	5.9 (2)	-	20.5 (2)	9.4 (8)
	Combined	-	6.9 (2)	4.2 (4)	6.8 (4)	15.4 (2)	18.4 (4)	10.1 (16)
Beauty Bay	Shallow	10.0 (1)	7.0 (2)	-	4.2 (4)	-	-	6.5 (5)
	Deep	10.0 (1)	6.9 (2)	4.0 (2)	5.0 (2)	20.3 (2)	-	9.1 (9)
	Combined	10.0 (2)	6.9 (4)	4.0 (2)	4.6 (4)	20.3 (2)	-	8.2 (14)
Higgins Point	Shallow	11.5 (1)	6.8 (2)	4.2 (2)	4.9 (2)	15.1 (2)	15.5 (2)	9.5 (11)
	Deep	-	6.5 (2)	4.1 (2)	4.6 (2)	15.0 (2)	15.3 (2)	9.1 (10)
	Combined	11.5 (1)	6.7 (4)	4.1 (4)	4.8 (4)	15.1 (4)	15.4 (4)	9.3 (21)
Mineral Ridge	Shallow	10.5 (1)	-	3.8 (1)	3.8 (2)	19.1 (2)	19.0 (2)	12.3 (8)
	Deep	9.6 (1)	7.1 (2)	4.0 (2)	3.9 (2)	14.6 (2)	15.0 (2)	9.0 (11)
	Combined	10.1 (2)	7.1 (2)	3.9 (3)	3.8 (4)	16.8 (4)	17.0 (4)	10.3 (19)
Mean	Shallow	10.7 (3)	7.1 (10)	4.4 (11)	5.5 (12)	16.1 (10)	16.7 (12)	10.0 (58)
	Deep	9.8 (2)	6.9 (14)	4.2 (14)	5.6 (14)	15.8 (12)	16.3 (12)	9.4 (68)
	Combined	10.3 (5)	7.0 (24)	4.3 (25)	5.5 (26)	16.0 (22)	16.5 (24)	

[a] F1 - F3 - newly placed fill
F4 - unaltered by highway construction

Table 9. Mean pH values determined from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date						Mean
		1980			1981			
I-90 Construction Site[a]		11 Nov.	19 Nov.	17 Dec.	20 Mar.	29 May	30 June	
F1	Shallow	-	7.1(2)	6.9(2)	6.5(2)	6.6(2)	7.4(2)	6.9(10)
	Deep	-	7.1(2)	6.8(2)	6.5(2)	6.2(2)	7.3(2)	6.8(10)
	Combined	-	7.1(4)	6.8(4)	6.5(4)	6.4(4)	7.3(4)	6.8(20)
F2	Shallow	-	7.0(2)	6.7(2)	6.4(2)	6.4(2)	7.2(2)	6.7(10)
	Deep	-	6.9(2)	6.6(2)	6.4(2)	6.5(1)	7.2(2)	6.7(9)
	Combined	-	7.0(4)	6.7(4)	6.4(4)	6.4(3)	7.2(4)	6.7(19)
F3	Shallow	-	6.9(2)	6.6(2)	-	-	7.3(2)	6.9(6)
	Deep	-	6.8(2)	6.5(2)	6.4(2)	6.4(2)	7.1(2)	6.6(10)
	Combined	-	6.9(4)	6.5(4)	6.4(2)	6.4(2)	7.2(4)	6.7(10)
F4	Shallow	-	-	6.4(2)	6.4(2)	6.5(2)	7.0(1)	6.6(8)
	Deep	-	6.7(2)	6.4(1)	6.4(2)	-	7.0(1)	6.7(7)
	Combined	-	6.7(2)	6.4(3)	6.4(4)	6.5(2)	7.0(4)	6.6(15)
Beauty Bay	Shallow	7.2(2)	7.0(2)	-	6.7(2)	-	-	7.0(6)
	Deep	7.3(2)	6.9(2)	6.7(2)	6.5(2)	6.3(2)	-	6.7(10)
	Combined	7.3(4)	7.0(4)	6.7(2)	6.6(4)	6.3(2)	-	6.8(16)
Higgins Point	Shallow	7.3(2)	7.3(2)	6.9(2)	6.6(2)	6.5(2)	7.3(2)	7.0(12)
	Deep	-	7.0(2)	6.9(2)	6.4(2)	6.7(2)	7.3(2)	6.8(10)
	Combined	7.3(2)	7.2(4)	6.9(4)	6.5(4)	6.6(4)	7.3(4)	6.9(22)
Mineral Ridge	Shallow	7.2(2)	-	6.7(1)	6.7(2)	6.6(2)	7.3(2)	6.9(9)
	Deep	7.1(1)	6.9(2)	6.6(2)	6.6(2)	6.2(1)	7.1(2)	6.8(10)
	Combined	7.2(3)	6.9(2)	6.7(3)	6.7(4)	6.4(3)	7.2(4)	6.8(19)
Mean	Shallow	7.2(6)	7.1(10)	6.7(11)	6.5(12)	6.5(10)	7.2(12)	6.8(61)
	Deep	7.2(3)	6.9(14)	6.7(13)	6.5(14)	6.4(10)	7.1(12)	6.7(66)
	Combined	7.2(9)	7.0(24)	6.7(24)	6.5(26)	6.4(20)	7.2(24)	-

[a] F1-F3 - newly placed highway fill
F4 - unaltered by highway construction

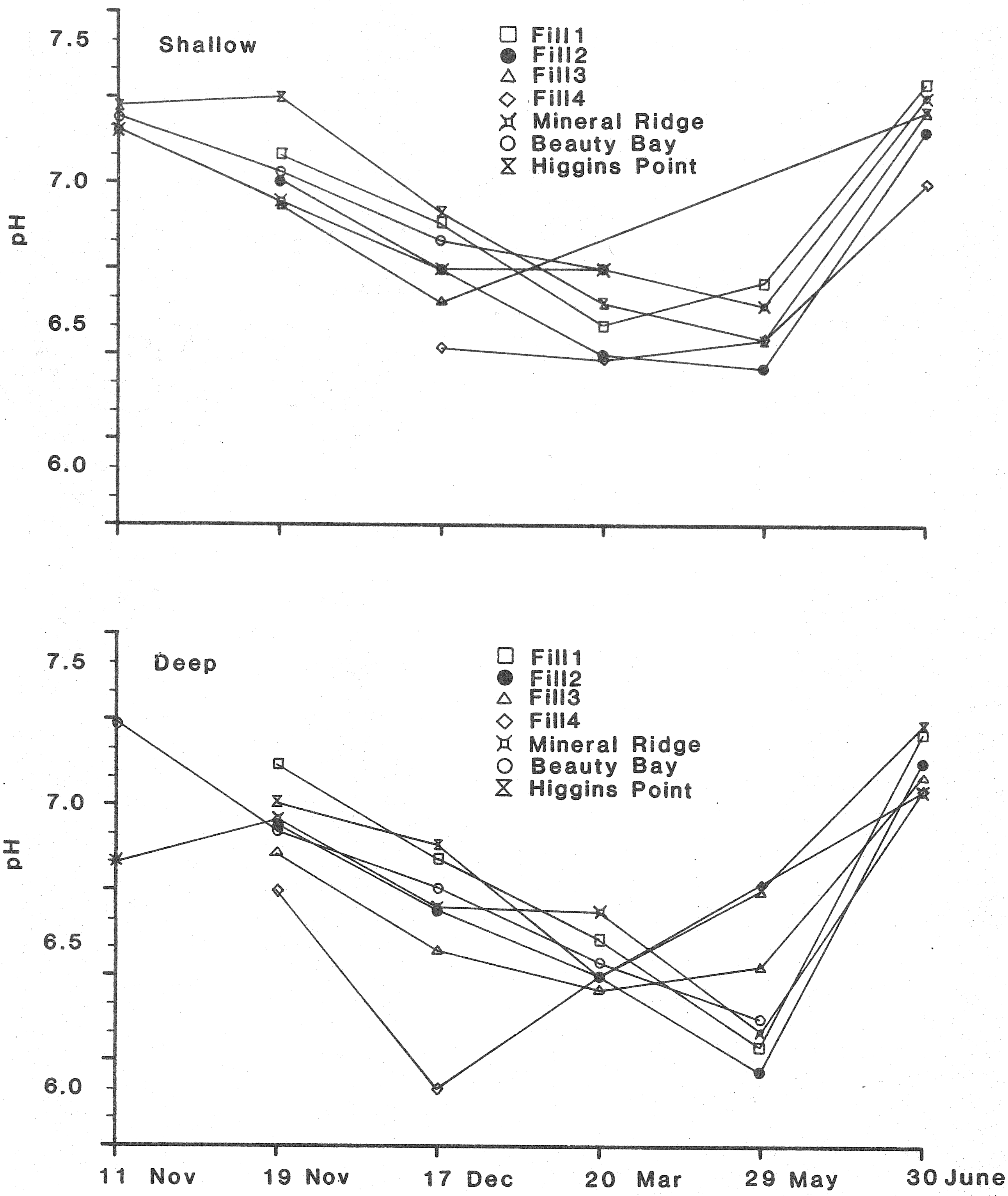

Figure 23. Intergravel pH values of samples collected from shallow and deep probes at seven locations in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, from November 1980 through June 1981.

Table 10. Mean dissolved oxygen levels determined from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ). Dissolved oxygen concentrations are in mg/l.

Site	Depth	Date						Mean
		1980			1981			
I-90 Construction Site[a]		11 Nov.	19 Nov.	17 Dec.	20 Mar.	29 May	30 June	
F1	Shallow	-	11.3(2)	7.0(2)	11.2(2)	8.5(2)	7.2(2)	9.0(10)
	Deep	-	11.0(2)	10.9(2)	11.1(2)	8.5(2)	8.2(2)	9.9(10)
	Combined	-	11.2(4)	9.0(4)	11.1(4)	8.5(4)	7.7(4)	9.5(20)
F2	Shallow	-	6.5(2)	6.2(2)	8.8(2)	7.5(2)	6.4(2)	7.0(10)
	Deep	-	10.9(2)	11.2(2)	11.2(2)	8.4(2)	8.5(2)	10.0(10)
	Combined	-	8.7(4)	8.7(4)	10.0(4)	7.9(4)	7.4(4)	8.5(20)
F3	Shallow	-	10.3(2)	11.0(2)	-	-	8.4(2)	9.9(6)
	Deep	-	8.5(2)	5.8(2)	10.2(2)	8.2(2)	5.3(2)	7.6(10)
	Combined	-	9.4(4)	8.4(4)	10.2(2)	8.2(2)	6.8(4)	8.5(16)
F4	Shallow	-	-	10.7(2)	8.8(2)	7.6(2)	7.1(2)	8.5(8)
	Deep	-	8.1(2)	7.8(2)	11.1(2)	-	4.7(2)	7.9(8)
	Combined	-	8.1(2)	9.2(4)	9.9(4)	7.6(2)	5.9(4)	8.2(16)
Beauty Bay	Shallow	11.3(1)	11.2(2)	-	12.0(2)	-	-	11.5(5)
	Deep	10.8(1)	8.6(2)	8.1(2)	8.5(2)	6.3(2)	-	8.2(9)
	Combined	11.1(2)	9.9(4)	8.1(2)	10.2(4)	6.3(2)	-	9.4(14)
Higgins Point	Shallow	11.8(2)	11.2(2)	11.7(2)	11.1(2)	9.4(2)	9.5(2)	10.8(12)
	Deep	-	10.8(2)	11.2(2)	11.6(2)	9.6(2)	8.6(2)	10.4(10)
	Combined	11.8(2)	11.0(4)	11.4(4)	11.4(4)	9.5(4)	9.2(4)	10.6(22)
Mineral Ridge	Shallow	11.0(1)	-	9.7(1)	9.6(2)	6.5(2)	5.8(2)	8.1(8)
	Deep	7.7(1)	7.0(2)	7.4(2)	6.9(2)	6.1(2)	5.7(2)	6.7(11)
	Combined	9.4(2)	7.0(2)	8.1(3)	8.4(4)	6.3(4)	5.7(4)	7.3(19)
Mean	Shallow	11.5(4)	10.1(10)	9.3(11)	10.3(12)	7.9(10)	7.4(12)	9.1(59)
	Deep	9.3(2)	9.3(14)	8.9(14)	10.1(14)	7.8(12)	6.9(12)	8.7(68
	Combined	10.7(6)	9.6(24)	9.1(25)	10.2(26)	7.8(22)	7.1(24)	

[a] F1-F3 - newly placed highway fill
F4 - unaltered by highway construction

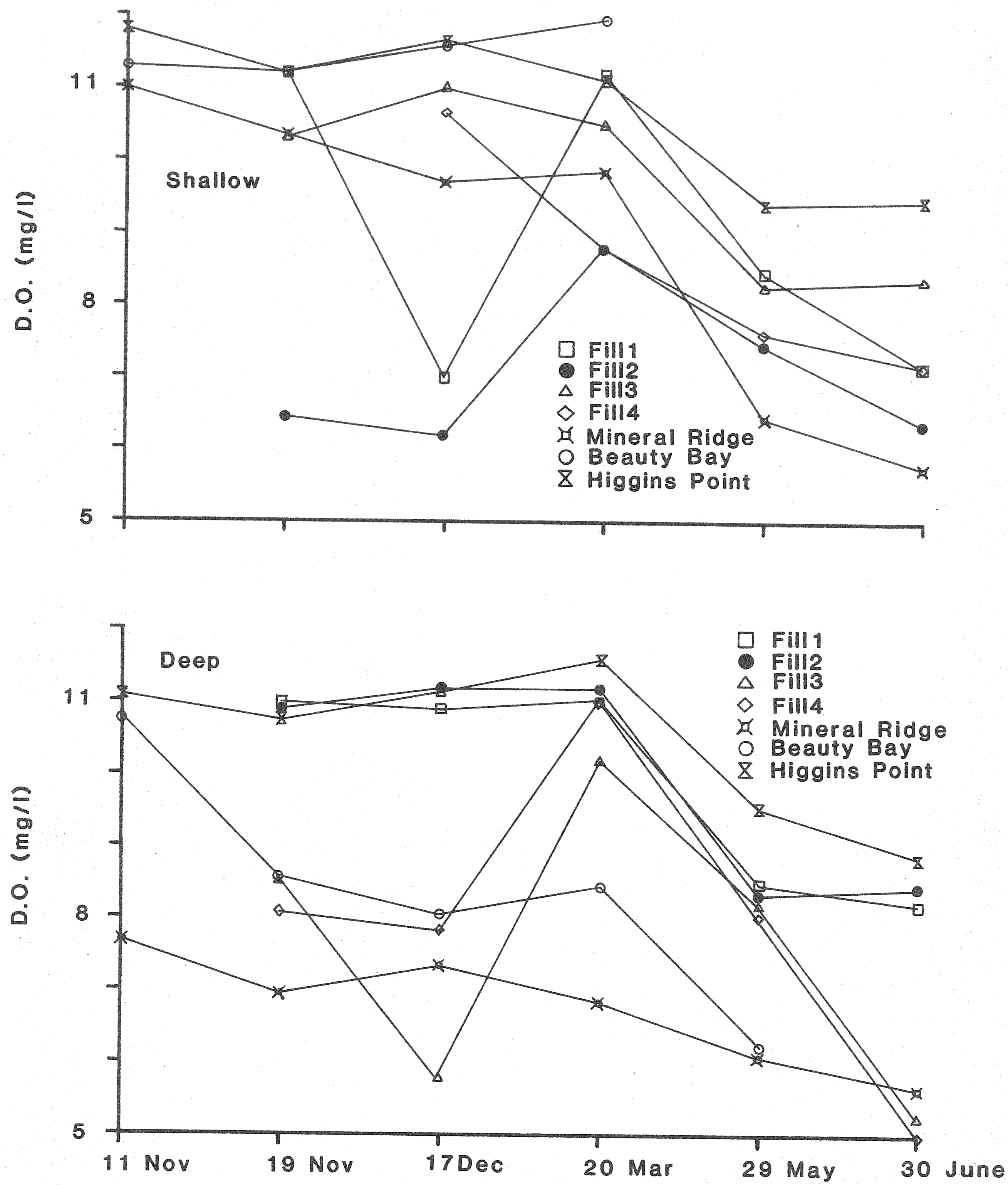

Figure 24. Intergravel dissolved oxygen levels (mg/l) from shallow and deep samples at seven locations in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, from November 1980 through June 1981.

Table 11. Mean alkalinity concentrations (meq/l) from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date						Mean
		1980			1981			
		11 Nov.	19 Nov.	17 Dec.	20 Mar.	29 May	30 June	
I-90 Construction Site[a]								
F1	Shallow	-	-	0.52 (4)	0.36 (4)	0.34 (4)	0.37 (4)	0.40 (16)
	Deep	-	-	0.45 (4)	0.38 (4)	0.28 (3)	0.38 (2)	0.38 (13)
	Combined	-	-	0.48 (8)	0.37 (8)	0.32 (7)	0.37 (6)	0.39 (29)
F2	Shallow	-	-	0.48 (4)	0.35 (4)	0.28 (4)	0.36 (3)	0.38 (15)
	Deep	-	-	0.41 (4)	0.35 (4)	0.35 (2)	0.40 (4)	0.38 (14)
	Combined	-	-	0.47 (8)	0.35 (8)	0.31 (6)	0.39 (7)	0.38 (29)
F3	Shallow	-	-	0.43 (4)	-	-	0.36 (3)	0.40 (7)
	Deep	-	-	0.47 (4)	0.33 (4)	0.33 (4)	0.44 (4)	0.39 (16)
	Combined	-	-	0.45 (8)	0.33 (4)	0.33 (4)	0.41 (7)	0.39 (23)
F4	Shallow	-	-	0.51 (4)	0.36 (4)	0.27 (4)	0.42 (4)	0.39 (16)
	Deep	-	-	0.50 (4)	0.35 (4)	-	0.37 (4)	0.41 (12)
	Combined	-	-	0.51 (8)	0.36 (8)	0.27 (4)	0.40 (8)	0.40 (28)
Beauty Bay	Shallow	0.62 (4)	-	-	0.40 (4)	-	-	0.51 (8)
	Deep	0.66 (4)	-	0.43 (4)	0.40 (4)	0.31 (4)	-	0.40 (16)
	Combined	0.54 (8)	-	0.43 (4)	0.40 (8)	0.31 (4)	-	0.44 (24)
Higgins Point	Shallow	0.45 (4)	-	0.40 (4)	0.40 (4)	0.33 (3)	0.39 (4)	0.40 (19)
	Deep	-	-	0.48 (4)	0.42 (4)	0.36 (4)	0.36 (2)	0.41 (14)
	Combined	0.45 (4)	-	0.44 (8)	0.41 (8)	0.35 (7)	0.38 (6)	0.40 (33)
Mineral Ridge	Shallow	0.44 (4)	-	0.45 (2)	0.44 (4)	0.51 (4)	0.58 (4)	0.49 (18)
	Deep	0.40 (4)	-	0.46 (4)	0.41 (4)	0.39 (2)	0.33 (4)	0.40 (18)
	Combined	0.42 (8)	-	0.45 (6)	0.43 (8)	0.47 (6)	0.45 (8)	0.44 (36)
Mean	Shallow	0.50 (12)	-	0.47 (22)	0.39 (24)	0.35 (19)	0.42 (22)	0.42 (99)
	Deep	0.43 (8)	-	0.46 (28)	0.38 (28)	0.33 (19)	0.38 (20)	0.40 (103)
	Combined	0.47 (20)	-	0.46 (50)	0.38 (52)	0.34 (38)	0.40 (42)	-

[a] F1-F3 = Newly placed fill
F4 = Unaltered by highway construction

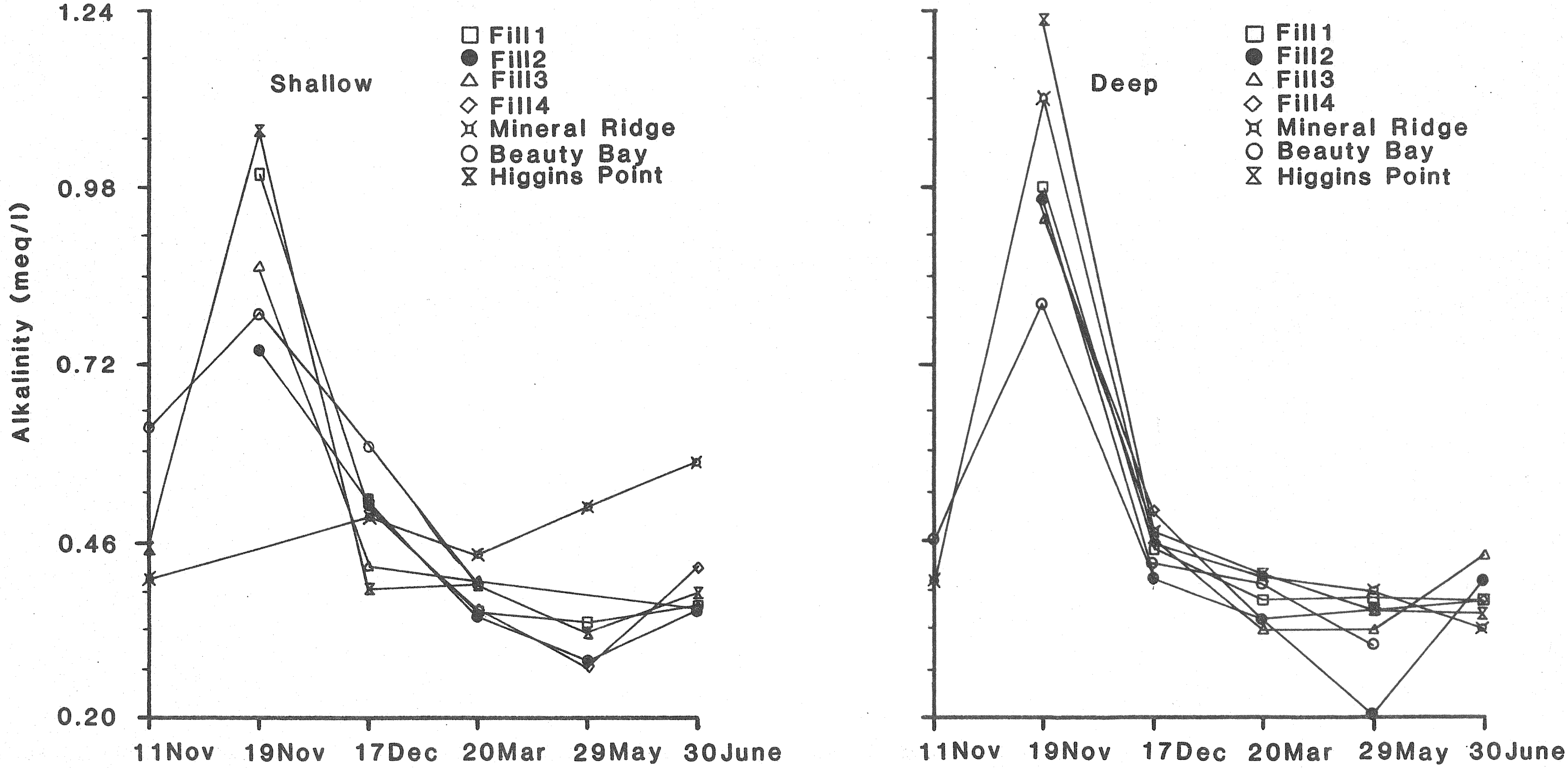

Figure 25. Intergravel alkalinity levels (expressed as meq/l) from shallow and deep probes at seven locations in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, from November 1980 through June 1981.

Table 12. Mean acidity concentrations (mg/l Ca CO_3) from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date						Mean
		1980			1981			
I-90 Construction Site[a]		11 Nov.	19 Nov.	17 Dec.	20 Mar.	29 May	30 June	
F1	Shallow	-	27.44 (3)	3.01 (4)	1.10 (4)	9.98 (4)	0.00 (4)	7.30 (19)
	Deep	-	15.62 (4)	16.08 (2)	0.45 (4)	21.00 (4)	0.00 (4)	10.02 (18)
	Combined	-	20.68 (7)	7.36 (6)	0.78 (8)	15.49 (8)	0.00 (8)	8.62 (37)
F2	Shallow	-	10.44 (4)	0.00 (4)	5.70 (4)	16.50 (4)	0.00 (4)	6.53 (20)
	Deep	-	11.95 (3)	0.00 (4)	3.95 (4)	20.00 (4)	0.00 (4)	6.93 (19)
	Combined	-	11.09 (7)	0.00 (8)	4.83 (8)	18.25 (8)	0.00 (8)	6.72 (39)
F3	Shallow	-	21.74 (3)	8.30 (4)	-	-	0.00 (4)	8.95 (11)
	Deep	-	8.33 (3)	4.72 (4)	3.20 (4)	10.33 (3)	0.00 (4)	5.48 (16)
	Combined	-	15.03 (6)	6.51 (8)	3.20 (4)	10.33 (3)	0.00 (6)	6.89 (27)
F4	Shallow	-	-	9.07 (4)	0.00 (4)	17.50 (4)	0.00 (4)	6.64 (16)
	Deep	-	30.27 (2)	12.60 (4)	2.05 (4)	-	0.00 (3)	9.16 (13)
	Combined	-	30.27 (2)	10.83 (8)	1.03 (8)	17.50 (4)	0.00 (7)	7.77 (29)
Beauty Bay	Shallow	2.07 (4)	13.81 (4)	-	19.54 (4)	-	-	11.81 (12)
	Deep	0.06 (4)	14.38 (2)	10.24 (4)	30.54 (3)	20.00 (4)	-	14.21 (17)
	Combined	1.06 (8)	14.00 (6)	10.24 (4)	24.25 (7)	20.00 (4)	-	13.21 (29)
Higgins Point	Shallow	0.00 (4)	28.77 (3)	20.35 (4)	17.54 (4)	15.60 (4)	0.00 (4)	13.05 (23)
	Deep	-	14.38 (4)	5.47 (3)	19.04 (4)	13.50 (4)	6.80 (4)	12.17 (19)
	Combined	0.00 (4)	20.55 (7)	13.97 (7)	18.29 (8)	14.55 (8)	3.40 (8)	12.66 (42)
Mineral Ridge	Shallow	0.96 (4)	-	53.20 (2)	18.04 (4)	8.00 (3)	0.00 (4)	12.14 (17)
	Deep	0.00 (4)	21.49 (2)	35.53 (4)	26.29 (4)	10.00 (2)	0.00 (4)	15.51 (20)
	Combined	0.48 (8)	21.49 (2)	41.42 (6)	22.17 (8)	8.80 (5)	0.00 (8)	13.96 (37)
Mean	Shallow	1.01 (12)	19.46 (17)	12.24 (22)	10.32 (24)	13.81 (19)	0.00 (24)	9.51 (118)
	Deep	0.03 (8)	15.66 (20)	12.04 (25)	11.54 (27)	16.62 (21)	1.30 (21)	10.67 (122)
	Combined	0.62 (20)	17.40 (37)	12.13 (47)	10.97 (51)	15.28 (40)	0.60 (45)	

[a] F1-F3 - newly placed highway fill
F4 - unaltered by highway construction

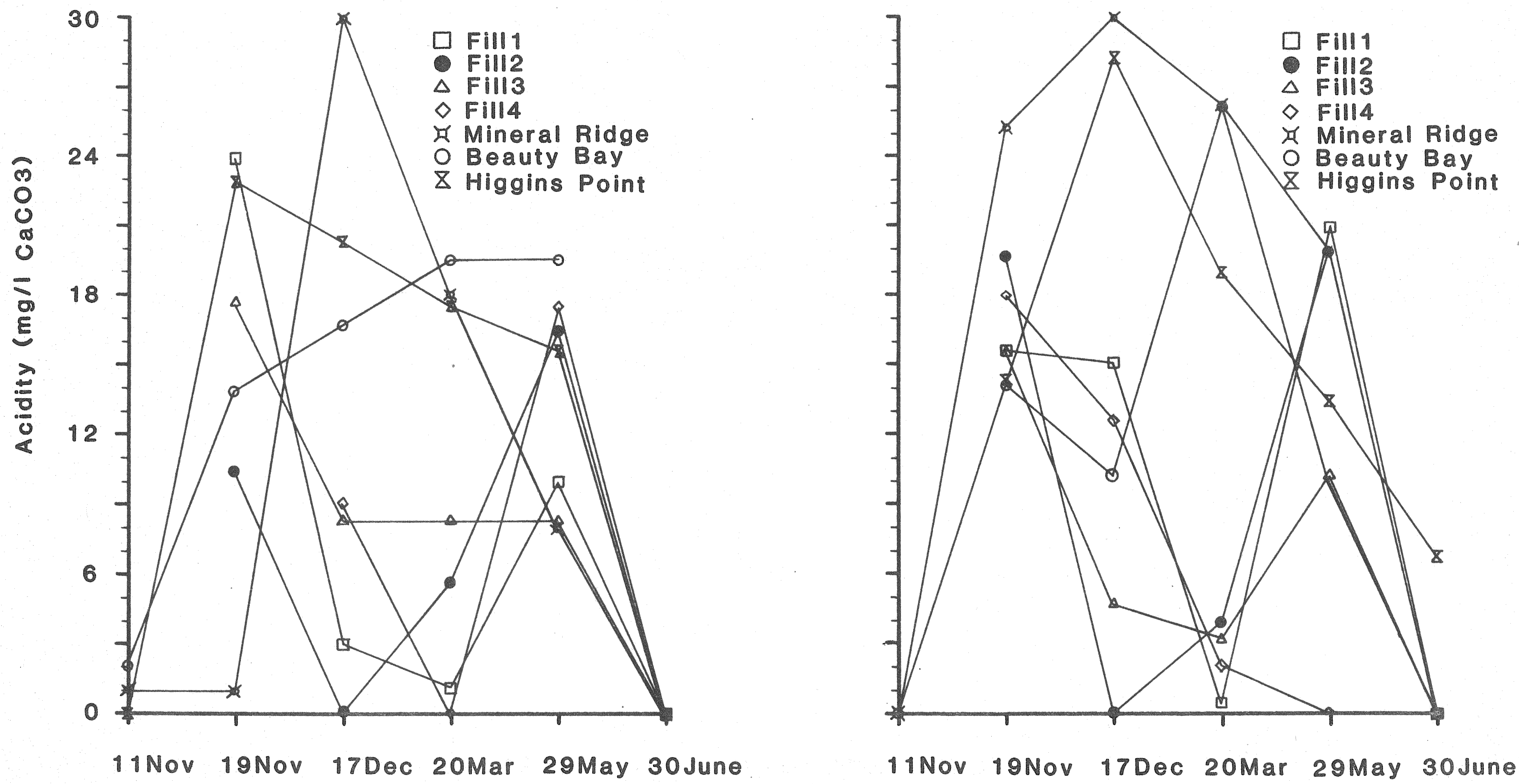

Figure 26. Intergravel acidity level (expressed as mg/1 CaC03) from shallow and deep probes at seven locations in Wolf Lodge Bay, Coeur d'Alene Lake, Idaho, from November 1980 through June 1981.

Acidity levels were significantly different among sites ($F=5.31$; $P=0.031$) and among dates ($F=20.84$; $P=0.0001$). Mean acidity levels were significantly lower at the I-90 Construction site locations (F1, F2, F3, and F4) than at Beauty Bay, Higgins Point, or Mineral Ridge (Table 12).

Ferrous iron and sulfate levels were extremely low for all samples. In many instances concentrations were below detection levels. Mean concentrations classified by site, date, and depth are listed in Tables 13 (ferrous iron) and 14 (sulfate).

DISCUSSION

Substrate Characterization

Analysis of substrates by photographic techniques proved to be effective for classifying kokanee spawning substrate in Coeur d'Alene Lake. Preferred spawning substrate was distinguished from other substrate by the D50 particle size and sorting coefficient. These two characteristics are easily interpolated from particle size-cumulative frequency distribution curves. Using this method, the size composition of a substrate sample can be described using various percentiles. Specific particle sizes for each sample need not be known to calculate the desired percentiles as they can be obtained graphically from the particle size-cumulative frequency distribution plots (Fig. 5). For example, we used particle size classes from 3.4 to 150 mm. This method minimized the amount of substrate analysis required to obtain values for desired particle sizes (D16, D50, D84).

Table 13. Mean ferrous iron concentration (mg/l) from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date 1980 11 Nov.	Date 1980 19 Nov.	Date 1980 17 Dec.	Date 1981 20 Mar.	Mean
I-90 Construction Site[a]						
F1	Shallow	-	-	0.34 (1)	0.00 (2)	0.11 (3)
	Deep	-	0.02 (1)	0.04 (1)	0.00 (2)	0.02 (4)
	Combined	-	0.02 (1)	0.19 (2)	0.00 (4)	0.06 (7)
F2	Shallow	-	-	0.00 (1)	0.00 (3)	0.00 (4)
	Deep	-	0.00 (2)	0.02 (1)	0.00 (2)	0.004 (5)
	Combined	-	0.00 (2)	0.01 (2)	0.00 (5)	0.002 (9)
F3	Shallow	-	0.01 (1)	0.00 (1)	-	0.005 (2)
	Deep	-	0.00 (1)	0.00 (1)	0.00 (2)	0.00 (4)
	Combined	-	0.005 (2)	0.00 (2)	0.00 (2)	0.002 (6)
F4	Shallow	-	-	0.01 (2)	0.00 (2)	0.005 (4)
	Deep	-	0.17 (1)	0.01 (1)	0.00 (2)	0.05 (4)
	Combined	-	0.17 (1)	0.01 (3)	0.00 (4)	0.03 (8)
Beauty Bay	Shallow	0.03 (2)	-	-	0.00 (2)	0.01 (4)
	Deep	-	0.00 (1)	0.00 (1)	0.13 (2)	0.06 (4)
	Combined	0.03 (2)	0.00 (1)	0.00 (1)	0.06 (4)	0.04 (8)
Higgins Point	Shallow	0.01 (2)	-	0.06 (1)	0.00 (3)	0.01 (6)
	Deep	-	0.03 (1)	0.00 (1)	0.00 (2)	0.01 (4)
	Combined	0.01 (2)	0.03 (1)	0.03 (2)	0.00 (5)	0.01 (10)
Mineral Ridge	Shallow	0.03 (1)	-	0.19 (1)	0.00 (2)	0.06 (4)
	Deep	-	0.04 (1)	0.02 (1)	0.00 (2)	0.02 (4)
	Combined	0.03 (1)	0.04 (1)	0.11 (2)	0.00 (4)	0.04 (8)
Mean	Shallow	0.02 (5)	0.01 (1)	0.09 (7)	0.00 (14)	0.03 (27)
	Deep	-	0.03 (8)	0.01 (7)	0.02 (14)	0.02 (29)
	Combined	0.02 (5)	0.03 (9)	0.05 (14)	0.01 (28)	

[a] F1-F3 - newly placed highway fill
F4 - unaltered by highway construction

Table 14. Mean sulfate concentration (mg/l) from interstitial water samples located at the I-90 Construction, Beauty Bay, Higgins Point, and Mineral Ridge sites, Wolf Lodge Bay, Coeur d'Alene Lake, Idaho. Shallow and deep samples were taken from piezometers placed 1.5 and 6.0 m below the surface, respectively. Sample sizes are also shown ( ).

Site	Depth	Date 1980 11 Nov.	1980 19 Nov.	1980 17 Dec.	1981 20 Mar.	Mean
I-90 Construction Site[a]						
F1	Shallow	-	-	3.80 (1)	3.50 (2)	3.60 (3)
	Deep	-	4.00 (1)	4.30 (1)	3.80 (2)	3.98 (4)
	Combined	-	4.00 (1)	4.05 (2)	3.65 (4)	3.81 (7)
F2	Shallow	-	-	4.30 (1)	3.60 (3)	3.78 (4)
	Deep	-	3.50 (2)	4.10 (1)	3.50 (2)	3.62 (5)
	Combined	-	3.50 (2)	4.20 (2)	3.56 (5)	3.69 (9)
F3	Shallow	-	3.80 (1)	4.40 (1)	-	4.10 (2)
	Deep	-	3.50 (1)	3.80 (1)	2.50 (2)	3.08 (4)
	Combined	-	3.65 (2)	4.10 (2)	2.50 (2)	3.42 (6)
F4	Shallow	-	-	3.85 (2)	2.40 (2)	3.13 (4)
	Deep	-	-	2.40 (1)	2.35 (2)	2.37 (3)
	Combined	-	-	3.37 (3)	2.38 (4)	2.80 (7)
Beauty Bay	Shallow	3.50 (1)	-	-	3.95 (2)	3.80 (3)
	Deep	-	3.35 (2)	3.50 (1)	2.95 (2)	3.22 (5)
	Combined	3.50 (1)	3.35 (2)	3.50 (1)	3.45 (4)	3.44 (8)
Higgins Point	Shallow	3.40 (1)	-	3.30 (1)	2.70 (3)	2.96 (5)
	Deep	-	3.30 (1)	4.10 (1)	3.60 (2)	3.65 (4)
	Combined	3.40 (1)	3.30 (1)	3.70 (2)	3.06 (5)	3.27 (9)
Mineral Ridge	Shallow	3.30 (1)	-	3.70 (1)	3.45 (2)	3.48 (4)
	Deep	-	3.90 (1)	4.00 (1)	2.95 (2)	3.45 (4)
	Combined	3.30 (1)	3.90 (1)	3.85 (2)	3.20 (4)	3.46 (8)
Mean	Shallow	3.40 (3)	3.80 (1)	3.89 (7)	3.25 (14)	3.47 (25)
	Deep	-	3.55 (8)	3.74 (7)	3.09 (14)	3.38 (29)
	Combined	3.40 (3)	3.58 (9)	3.81 (14)	3.17 (28)	-

[a] F1-F3 - newly placed highway fill
F4 - unaltered by highway construction

Substrate Utilization

The apparent clustering of samples utilized for spawning on the D50 vs sorting coefficient plot for all sites combined (Fig. 9) revealed that both values are critical factors for describing preferred kokanee spawning habitat. Most spawning in Coeur d'Alene Lake occurred on moderate sized substrate (50th percentile particle size range = 21 to 90 mm) of rather uniform composition. Low sorting coefficients within the preferred range reflect small differences (3 to 10 fold) between the 16th and 84th percentile particle sizes. In other words, most of the substrate sample falls within a narrow particle size range, indicating relatively homogeneous particle size composition. The three-dimensional plots verified this interpretation (Figs. 14-17). These plots indicated that substrate used for spawning is typically that with low to moderate D50 and D84 values and low sorting coefficients (approximately less than 1.0). Samples with low to moderate D50 and D84 values but high sorting coefficients were probably not utilized for spawning due to the larger amount of fines present. Those samples not utilized for spawning with high D50 and D84 values and low sorting coefficients were relatively homogeneous in size but too large to be used by kokanee for spawning.

Little comparative information is available on the size composition of substrate for spawning kokanee. In Odell Lake, Oregon, lakeshore spawning kokanee selected gravel from 3.18 to 25.4 mm in diameter (Averett and Espinosa 1968). Hoopes (1972) found sockeye salmon spawning in three streams tributary to Brooks Lake, Alaska, in substrate with intermediate sized particles (94% of the particles, by weight, less than 76 mm), with little spawning in substrate where particles were either very large or very small. Kokanee spawned on talus lakeshore slopes in Banks Lake, Washington, on substrate particles ranging from 2 to 150 mm in diameter (Stober et al. 1977). From our work, kokanee in Coeur d'Alene Lake are selecting similar sized particles for spawning. Selection of similar sized substrate for kokanee embryo deposition in Coeur d'Alene Lake was unexpected because of the small size of spawning fish. Mean size of female spawners taken throughout the spawning season in Lake-Merwin traps set in shoreline areas of Wolf Lodge Bay and Beauty Bay (both adjacent to Mineral Ridge) in 1980 was 23.9 cm (Bruce Rieman, Idaho Department of Fish and Game, personal communication).

Extent of Spawning Utilization

Of prime importance to this study was the finding that kokanee did utilize the new fill area for spawning. In Banks Lake, Washington, Stober et al. (1979b) found that kokanee did not utilize artificially constructed spawning habitat for two years following placement of the substrate (this substrate was only surveyed for two years following its placement). Spawning overlay and fractured fill substrates were both utilized by spawning kokanee over the entire I-90 Construction Site fill. Utilization of spawning overlay (33%) was lower than utilization of fractured fill (45%). Although spawning overlay was not used as extensively as fractured fill at the I-90 Construction Site, the overlay provided additional spawning habitat where the underlying fractured fill was too large to be utilized for spawning.

Transect analysis revealed kokanee utilized some substrate in all areas surveyed for spawning. Twenty-eight percent of the total area surveyed at all study sites was utilized for spawning (Table 3), indicating the concentrated spawning activity in this area of Wolf Lodge Bay. Also of interest, was that the percent of total substrate used for spawning was similar among sites.

Kokanee spawning on substrate classified as preferred varied among sites and was lowest at the I-90 Construction site (Table 3). The I-90 Construction site constituted a vast area, of which 61% was preferred spawning substrate, and spawning activity was dispersed over the entire area. Percentages of potential spawning substrate at the I-90 West and Beauty Bay sites were lower (23-29%) than at the I-90 Construction Site (Table 3), and suitable substrate existed in localized areas rather than being dispersed over the entire area surveyed. At the Beauty Bay and I-90 West sites, spawning activity was concentrated on these localized areas, resulting in the high degrees of utilization of preferred spawning substrate at these sites (67 and 100%). Availability of preferred spawning substrate at the Mineral Ridge site was moderate (26%), with high spawning utilization of preferred substrate (78%). High spawning utilization at Mineral Ridge was probably a result of this area being an established spawning area which has not undergone recent modifications.

Assessing substrate utilization using emergent fry traps showed 100% utilization by spawning kokanee of all substrate sampled. We believe that the small number of traps used was not adequate to quantify substrate utilization. Since our SCUBA surveys were conducted at the peak of spawning activity, transect analysis represents a minimum estimate of spawning substrate utilization. We do feel, however, that transect analysis probably provided a more accurate estimate of spawning substrate utilization. Capture of fry in a number of emergent fry traps may have resulted from lateral intergravel movement of fry prior to emergence, a factor which we could not quantify. Laboratory tests have confirmed that lateral movement occurs, but this factor has not been quantified. The large size and irregular shape of fractured fill material combine to produce large interstitial spaces, allowing nearly unrestricted lateral movement of pre-emergent fry. Instability of the spawning overlay, due to steepness of the slope and round nature of the particles, resulted in displacement of many traps on this substrate. Down-slope movement resulted in traps fishing a larger area than they actually covered. However, use of the traps did verify utilization by spawning kokanee of the substrate areas sampled, as well as fry emergence from these areas.

Embryo Survival and Emergence Success

Although our estimates of kokanee fry emergence were highly variable, emergence success from planted kokanee embryos was ostensibly high at all sites except at Beauty Bay. Because of this variability, we believe that survival to the pre-emergent fry stage was a better estimate of emergence success than emergent fry trap captures. Using survival to the pre-emergent fry stage emergence success ranged from 23 to 60% at the I-90 construction site and Mineral Ridge sites. In contrast, in Banks Lake, Washington, kokanee emergence success was 23.88, 11.92, and 2.13% (most liberal estimates made) of potential egg deposition in 1977, 1978, and 1979, respectively (Stober et al. 1979b). Kokanee in Banks Lake spawned on fractured material (though smaller) on steep lakeshore slopes, similar to those in Coeur d'Alene Lake.

The high survival of embryos in substrate composed of fractured particles in Coeur d'Alene Lake may be enhanced by the porosity of the substrate. Numerous studies (primarily in flowing waters) have shown porosity and permeability to increase with increasing particle size. In standing waters, it would be advantageous from the standpoint of pre-emergent embryo survival to have substrate with high permeability and/or porosity, thus allowing more interstitial water movement. Embryo survival has been positively correlated with interstitial water movement (Cooper 1965). The seemingly high porosity of the fractured substrates as a result of the highway fill would enhance survival by allowing unrestricted movement of water through the substrate, continuously "bathing" the developing embryos in fresh water. Reduced porosity in the spawning overlay may be one reason why reduced pre-emergent survival was observed (Table 5). Although reduced survival occurred on the spawning overlay, the net effect of the overlay was to provide additional habitat with preferred size substrate.

Significantly lower survival to the pre-emergent fry stage was found at deep water sites than at shallow water sites (Table 5). Although we did not measure intragravel water movement at deep and shallow sites, we believe that increased intragravel water movement at shallow sites probably accounted for higher survival to the pre-emergent stage. These data indicate the importance of creating high quality spawning, incubating, and emergence habitat in shallow areas ($\leq$ 10 m) of the lake in future construction activities. Therefore, creation of vertical strips of suitable spawning substrate in Coeur d'Alene Lake would be less desirable than providing preferred size substrate (D50 21-90 mm with sorting coefficient 0.50-1.05) in shallow areas. Preferred size substrate might be maintained in the upper 10 m (7 m + 3 m fluctuation) below summer pool by creating "benches" or shelves to preclude deeper gravel movement.

Our observations of deep spawning kokanee in Coeur d'Alene Lake did not indicate whether fish were spawning at deeper depths as a displacement function (a result of high densities) or whether fish were manifesting spawning habitat selection (Hassemer and Rieman 1981). Kokanee spawning as deep as 20 m in Coeur d'Alene Lake appears to be unique. Most available information suggests kokanee and sockeye salmon spawning occurs in the upper 6 m (Lindsay and Lewis 1978; Olsen 1968; Stober et al. 1979a). Although our observations and those of Hassemer and Rieman (1981) indicate deep spawning by kokanee in Coeur d'Alene Lake occurs, results of our egg planting experiments suggest decreased survival occurs below 7 m (Table 5).

Fry Quality

Survival of fry in open water is dependent on fitness of the fry at emergence. Condition of fry is partly attributable to environmental conditions during intergravel stages. Stress on developing embryos and fry during the intragravel period can result in consumption of food reserves which would otherwise be used for growth (Koski 1975).

In this study, fry quality was analyzed with respect to natural undisturbed substrates and highway fill substrates that were utilized for spawning. Besides expected temporal differences in fry quality indices, differences in these indices were not significant among sites. Our analyses indicate the presence of fill material does not subject developing embryos and alevins to any sublethal stress which would reduce their survival potential relative to embryos and alevins incubated in other areas. Non-significant differences in development stages among sites indicated that fry developed at approximately the same rate (Table 6).

Substrate-Water Analyses

Substrate-water analyses revealed no adverse concentrations of selected water chemistries monitored. Levels of pH were the major concern in this study due to the high pyritic concentrations of the fill material. Summarization of studies on the effects of acid stress on fish has led to the conclusion that pH within the range 5.0 to 9.0 is generally non-toxic, although toxicity within this range is governed by other chemical factors (EIFAC 1969). Throughout this study mean pH did not range below 6.4 and generally remained near neutral (6.7 - 6.9). Based on our studies, the highway fill material placed in Coeur d'Alene

Lake did not cause a reduction in pH and therefore, did not adversely affect the survival potential of embryos incubating within highway fill substrate. However, continued monitoring of pH and acidity is recommended because of the potential for adverse water quality conditions developing with time. High survival rates to the various life stages examined support our conclusion that lethal levels of selected water chemistries monitored were not present during the course of this study.

Further Alterations From Highway Construction Activities

Results of our studies on the newly placed I-90 highway construction fill suggest the importance of suitable sized substrate for kokanee spawning. We believe that further alterations to the shoreline of Coeur d'Alene Lake by highway construction could have potentially beneficial effects on kokanee spawning success if substrate of suitable size and chemical composition was used. Our results indicated that particle size composition in the D50 range of 21-90mm with a sorting coefficient of 0.50-1.05 was preferred by spawning kokanee. Substrate outside of these ranges was poorly utilized (23% of fish) and therefore, would not provide adequate spawning substrate for kokanee. Concern was expressed because of possible degradation from pyrite in the fill (concentrations to 5% - Hobbs et al. 1965); however, we did not observe changes in water quality during the first year as a result of the fill. Although the potential for decreased water quality exists as the result of aging of newly placed fill, similar concentrations for water quality parameters monitored during the study on Mineral Ridge should alleviate most of these concerns as Mineral Ridge also was altered by highway construction approximately 15 years ago.

Our results provide reason for optimism about the effects of fill from highway construction activities on spawning, incubation, and emergence of kokanee in Coeur d'Alene Lake. These results, however, cannot be interpreted to represent the response of other stocks of kokanee or other species of fish to highway fill. Habitat requirements among fish stocks differ and, therefore, our results must be applied only to kokanee stocks in Coeur d'Alene Lake.

Summary

1) Analysis of underwater photographs and water samples and enumeration of fry survival in emergent fry traps were used from October 1980 through June 1981 to evaluate the suitability of newly placed fill material from I-90 construction activities on the spawning success on kokanee salmon. Samples taken from the I-90 study site (fractured fill and spawning overlay) were compared to those from an old highway construction site and two unaltered sites.

2) Kokanee utilized recently placed highway fill areas for spawning at about the same proportion as other areas; kokanee at all sites demonstrated strong preference for substrate with a specific particle size composition (D50 21-90 mm; sorting coefficient 0.50-1.05).

3) Survival of kokanee embryos to the eyed egg and pre-emergent stages was similar between newly placed highway fill and areas of old highway fill; however, survival at new and old highway fills was generally higher than that from unaltered areas.

4) Analysis of interstitial water samples taken prior to, during, and at the time of emergence revealed dissolved oxygen, pH, alkalinity, acidity, ferrous iron, and sulfate were within the range of acceptable levels for kokanee embryo incubation and fry emergence and were generally similar among study sites.

5) Further alterations of Coeur d'Alene Lake shoreline associated with highway construction activities could be made with additional beneficial effects to spawning, incubation, and emerging kokanee if fill were of similar design criteria, size, and mineral composition to the fill investigated in this study. Because significantly lower survival to the

pre-emergent fry stage was found at deep water sites than at shallow sites, further construction activities should ensure the placement of preferred sized homogeneous substrate (D50 - 21-90 mm sorting coefficient 0.50 - 1.05) in shallow areas (< 10 m) of the lake.

6) Our results indicate that spawning success of kokanee in Coeur d'Alene Lake has been enhanced by the addition of fill as a result of highway construction activities in the north end of the lake.

Acknowledgments

Funding for this project was provided by the Idaho Transportation Department. The assistance given by personnel of the Idaho Department of Fish and Game (IDFG) in securing funding, project design, and in the field was greatly appreciated. Bruce Rieman of IDFG was especially helpful. Report preparation was aided by the College of Forestry, Wildlife, and Range Sciences, University of Idaho. Thanks are extended to Gary Bertelotti, Jon Cavigli, Tom McArthur, and Barb Mitchell for helping with field work and laboratory analysis.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Idaho Transportation Department.

REFERENCES

Averett, R. C. and F. A. Espinosa, Jr. 1968. Site selection and time of spawning by two groups of kokanee in Odell Lake, Oregon. Journal of Wildlife Management. 32(1):76-81.

Bams, R.A. 1970. Evaluation of a revised hatchery method tested on pink and chum salmon fry. Journal of the Fisheries Research Board of Canada. 27(8):1429-1452. Canada.

Bowler, B. 1980. Kokanee life history studies in Coeur d'Alene Lake. Idaho Department of Fish and Game - Lake and Reservoir Investigations. Job Performance Report F-73-R-2, Study V, Job No. 3. Boise, Idaho, USA.

Cooper, A.C. 1965. The effects of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. International Pacific Salmon Fisheries Commission. New Westminster, British Columbia, Canada. In Platts, W.S., M.A. Shirazi, and D.H. Lewis. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency. EPA-600/3-79-043. Corvallis, Oregon, USA.

Environmental Protection Agency (EPA). 1974. Methods for chemical analysis of water and wastes. Methods Development and Quality Assurance Laboratory. National Environmental Research Center. Cincinnati, Ohio. EPA-625-/6-74-003.

European Inland Fisheries Advisory Commission (EIFAC). 1969. Water quality criteria for European freshwater fish - extreme pH values and inland fisheries. Water Research 3:593-611.

Hassemer, P. F. and B. E. Rieman. 1981. Observations of deep-spawning kokanee on artificially created spawning habitat. North American Journal of Fisheries Management. 1:173-176.

Hassemer, P. F. and B. E. Rieman. 1980. Coeur d'Alene Lake spawning evaluations. Idaho Department of Fish and Game - Lake and Reservoir Investigations. Job Performance Report F-73-R-2, Study V, Job No. 3. Boise, Idaho, USA.

Hobbs, S. W., A. B. Griggs, R. E. Wallace, and A. B. Campbell. 1965. Geology of the Coeur d'Alene District, Shoshone County, Idaho. U.S. Geological Service. Geological Survey Professional Paper 478.

Hoopes, D. T. 1972. Selection of spawning sites by sockeye salmon in small streams. Fishery Bulletin 70(2):447-458.

Koski, K. V. 1975. The survival and fitness of two stocks of chum salmon (Oncorhychus keta) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. Dissertation. University of Wash. Seattle, USA. *in* Stober, Q. J., R. W. Tyler, C. F. Cowman, J. Wicock and S. Quinnell. 1979b. Irrigation drawdown and kokanee salmon egg to fry survival in Banks Lake.

Lindsay, R. B. and S. L. Lewis. 1978. Kokanee ecology. Oregon Department of Fish and Wildlife, Lake and Reservoir Investigations. Final D-J Report F-71-R. Portland, Oregon, USA.

Mallet, J. 1968. Coeur d'Alene Lake Fisheries investigations. Idaho Department of Fish and Game. Job Performance Report. Boise, Idaho, USA.

Olsen, J. C. 1968. Physical environment and egg development in a mainland beach area and an island beach area of Hiamna Lake. Pages 169-197 *in* R. L. Burgner, editor. Further studies of Alaska sockeye salmon, University of Washington Publications in Fisheries. New Series, Volume III. University of Washington Press. Seattle, Washington, USA.

Ott, L. 1977. An introduction to statistical methods and data analysis. Duxbury Press. North Scituate, Massachusetts, USA.

Platts, W.L., M.S. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency. EPA-600/3-79-043. Corvallis, Oregon, USA.

Rieman, B.E. 1980. Coeur d'Alene Lake limnology. Idaho Department of Fish and Game - Lake and Reservoir Investigations. Job Performance Report F-73-R-2, Study V, Job No. 3. Boise, Idaho, USA.

Rieman, B.E. and L. LaBolle. 1980. Coeur d'Alene Lake creel census. Idaho Department of Fish and Game - Lake and Reservoir Investigations. Job Performance Report F-73-R-2, Study V, Job No. 1. Boise, Idaho, USA.

Stober, Q.J., R.W. Tyler, J.A. Knutzen, D. Gaudet, C.E. Petrosky, and R.E. Nakatani. 1977. Operational effects of irrigation and pumped storage on the ecology of Banks Lake, Washington. Bureau of Reclamation, REC-ERC-77-5, Denver, Colorado, USA.

Stober, Q.J., R.W. Tyler, C.E. Petrosky, K.P. Johnson, C.F. Cowman, Jr., J. Wilcock, and R.E. Nakatani. 1979a. Development and evaluation of a net barrier to reduce entrainment loss of kokanee from Banks Lake. Fisheries Research Institute. Final Report. Contract Number 7-07-10-50023 with the U.S. Bureau of Reclamation. University of Washington, Seattle, Washington, USA.

Stober, Q.J., R.W. Tyler, C.F. Cowman, Jr., J. Wilcoxk, and S. Quinnell. 1976b. Irrigation drawdown and kokanee salmon egg to fry survival in Banks Lake. Fisheries Research Institute - University of Washington, Seattle, USA. Contract number 7-07-10-S0023 with the U.S. Bureau of Reclamation.